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Environmental governance effects of local environmental protection expenditure in China

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A B S T R A C T

China’s economy is experiencing a rapid revival in the post Covid-19 era, while energy consumption is surging and environmental pressure is prominent. Environmental protection expenditure is an important means for local governments to improve environmental quality; it plays a crucial role in guiding market investment, providing environmental treatment funds and energy conservation and utilization. Based on a sample of 286 prefecture-level cities in China from 2007 to 2017, this study analyzes environmental governance effects of local environmental protection expenditure while considering the time duration, regional differences, and spatial spillover characteristics of industrial pollution emissions. The results reveal that local environmental protection expenditure could help reduce industrial pollution emissions in Chinese cities; however, the governance effects were heterogeneous in different clustering city groups. In addition, the effects of environmental protection expenditure at the neighborhood level varied greatly; the results showed that the stronger the spillover of pollutants, the more significant was the trans-regional governance effect of local environmental protection expenditure. Therefore, local governments should promote a cooperative mode of “joint prevention and control and cross-regional governance” when treating pollutants with strong spillover potential.

1. Introduction

China’s economy has entered a “new normal” stage in which economic development has gradually shifted from the pursuit of growth to that of structural adjustment and environmental efficiency (Hilton and Kerr, 2017; Yan et al., 2019). However, the rapid recovery of China’s economy in the post Covid-19 era may cause a surge in energy demand and highlight environmental pressure. How to improve environmental quality without sacrificing domestic economic growth and achieve a “win-win” effect between economic development and environmental protection is the key to the smooth realization of sustainable development (Elzen et al., 2016; Song et al., 2020a). As the main source of China’s environmental problems, industrial pollution has been effectively controlled after years of efforts, but the problems of time duration and spatial spillover of pollution emissions still exist (Fan et al., 2021). Consequently, the government is working to address these challenges.

According to the theory of public finance and externalities, environmental pollution has obvious negative externalities. Negative externalities contribute to differences between private and social net marginal costs and lead to the misallocation of resources and low social efficiency. At present, the market alone may not solve the externality problem of environmental pollution, thereby creating a so-called “market failure.” Previous studies indicate that three kinds of measures are typically adopted to handle environmental pollution in some main countries or regions. First, governments may levy taxes against producers of negative externalities to effectively achieve the internalization of external costs (Goulder and Schein, 2013; Marron and Toder, 2014). Second, governments may take a supervisory position over negotiations between the polluters and pollution victims; the parties may negotiate to clarify property rights, after which a property rights trading system may be used to achieve the Pareto optimal production efficiency balance between enterprises (Zhang and Wei, 2010; Perthus and Trogignon, 2014). Third, increased government expenditure may be used to encourage producers to technologically innovate and produce cleaner

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products (Adewuyi, 2016; Halkos and Paizanos, 2016). Therefore, studying the government’s environmental governance effects cannot only improve the environmental quality of a country or region, but also reduce the burden of countries’ demand for fossil energy and maintain energy security in the post Covid-19 era.

At present, China’s pollution control relies heavily on government regulation, especially in the revenue and expenditure activities of governments at all levels (Ma et al., 2019; Chai et al., 2020; Cheng et al., 2021a). As an important means for local governments to govern the environment, fiscal expenditure will have a direct or indirect impact on the environmental quality of their jurisdiction. For example, López et al. (2011) conducted an empirical study on air and water pollutants and found that increasing total government expenditure cannot effectively reduce pollution, but the redistribution of government expenditure structure to society and public goods can reduce pollution. Adewuyi (2016) believed that the environmental governance effect of government expenditure can show the opposite effect in the short term and long term. Research by Galinato and Galinato (2016) showed that fiscal expenditure indirectly can affect environmental pollution through energy consumption in the supply of public goods and services. The above studies have confirmed that government expenditure does have an impact on environmental pollution, but no consensus has been reached on the action mechanism or impact path.

In the government expenditure structure, expenditure on environmental protection is the most common governmental expenditure related to environmental governance. In 2007, China reformed its classification of government revenue and expenditure. For the first time, the “211 environmental protection” item was set as a “category” of the fiscal budgets and final accounts. After 2011, this category was renamed as “energy conservation and environmental protection” to emphasize the government’s expenditure on environmental protection. To maintain the consistency of naming, “environmental protection expenditure” is the term used throughout this manuscript. “Environmental protection expenditure” includes specific expenditures related to environmental protection management, environmental monitoring and supervision, and pollution control (Ministry of Finance, 2018). Since the establishment of the subject of environmental protection expenditure, many scholars have studied the environmental governance effect of local environmental protection expenditure in China with cross annual provincial panel data (Fan et al., 2020; Pan et al., 2020; Cheng et al., 2021b). The research methods mainly involve the Spatial Econometric (Huang, 2018) and Game (Fan et al., 2021) model approaches, and the Logarithmic Mean Divisia Index (LMDI) approach (Cheng et al., 2021b). Previous results have shown that local environmental protection expenditure plays a direct and significant role in controlling industrial pollutants and greenhouse gas emissions.

The existing literature draws from a variety of different data and methods to discuss the environmental governance effects of local fiscal expenditure in China. It provides beneficial references for achieving sustainable development across the country and within different regions; however, some deficiencies exist: first, most studies are based on the total amount of controlled pollution emissions, and few comprehensively consider the characteristics of time duration, regional differences, or the spatial spillover of pollution emissions. Second, the literature on the environmental governance effects of expenditure structure are mostly based on geographical (e.g., eastern, central, and western) or administrative regions (e.g., provinces). Existing literature is likely to ignore differences in city endowments regarding socio-economic parameters, such as gross domestic product (GDP), population, the industrial structure and other social and economic factors that affect pollution emissions. These factors have strong path dependence and are difficult to adjust in the short term.

This study expands on the existing literature in two key ways: (1) it considers the time duration, regional differences, and spatial spillover characteristics of China’s industrial pollution emissions, while the environmental governance effect of local environmental protection expenditure is investigated from the city dimension, strongly promoting the country’s sustainable development. (2) Through hierarchical cluster analysis (HCA), this study focuses on the environmental governance effects within and between clustering city groups. Compared with the previous literature, this study breaks through the limitations of geographical and administrative divisions, while at the same time highlighting the environmental governance effect of local governments and providing a feasible scheme for effectively setting differentiated emission reduction and energy utilization policies.

The remainder of the paper is structured as follows: Section 2 introduces the data, variables, and application of the entropy weight method, HCA, dynamic system Generalized Method of Moments (GMM) model, and the Spatial Panel model. Section 3 offers the results and discussion, focusing on the environmental governance effects of China’s local environmental protection expenditure, and further expands upon regional differences and spatial spillovers of emissions. Section 4 provides conclusions and policy implications.

2. Methods and data

2.1. Hierarchical cluster analysis

In order to identify cities with similar socio-economic endowment and explore the impact mechanism of local environmental protection expenditure on environmental pollution in different cities, referring to the practices of scholars such as Arbolino et al. (2019), Wang et al. (2020), and Cheng et al. (2021a), this study adopts HCA to cluster cities with similar socio-economic endowments first, and then focuses on the environmental governance effect of local environmental protection expenditure on each clustering city group, so as to provide a feasible scheme for the country to effectively set differentiated emission reduction policies.

The advantages of HCA are: (1) the similarity between distance and rule is easy to define and has few restrictions; (2) there is no need to formulate the number of clusters in advance; and (3) the hierarchical relationship of clusters can be readily identified. The distance between clusters is measured using the Between-Groups Linkage method, which uses the average of the squared variable distances between cities to measure the distance between classes; this is also known as the Average Linkage (Nasibov and Kandemir-Cavas, 2011), and is represented by the following equation:

$$D^2_{ji} = \frac{1}{n_p} \sum_{k \in G_i} \sum_{q \in G_j} d^2_{kq}$$

(1)

where $x_i$ and $x_j$ are two cities that belong to Cluster $G_p$ and Cluster $G_q$, respectively; $n_p$ and $n_q$ are the number of cities in each cluster; and $d_{kq}$ is the distance between city $i$ and city $j$. Further, the Cluster $G_p$ and Cluster $G_q$ are merged into a new Cluster $G_r$, and the distance between $G_r$ and $G_i$ is calculated as follows:

$$D^2_{ir} = \frac{1}{n_r} \sum_{k \in G_r} \sum_{l \in G_i} d^2_{kl}$$

$$= \frac{1}{n_r} \left( \sum_{k \in G_p} \sum_{l \in G_i} d^2_{kl} + \sum_{k \in G_q} \sum_{l \in G_i} d^2_{kl} \right)$$

$$= \frac{n_p}{n_r} D^2_{pi} + \frac{n_q}{n_r} D^2_{qi}$$

(2)

where $x_i$ and $x_j$ are two cities that belong to $G_r$ and $G_i$, respectively, and $n_p$ and $n_q$ are the city capacity of each cluster. In addition, the variable distance between city $i$ and city $j$ is measured by the most common Squared Euclidean Distance (Gough, 2001).

2.2. Dynamic system GMM model

Due to a certain duration of time associated with industrial pollution...
emissions, the Dynamic Panel model is adopted to provide an estimate in this study. In this model, the unobservable individual effects and time-fixed effects are controlled by difference or instrumental variable methods, and the lag periods of explanatory variables and explained variables are taken as instrumental variables; this can effectively overcome the endogenous problem when better exogenous variables cannot be obtained. In addition, compared with the differential GMM model, the system GMM model greatly improves the estimation efficiency and can estimate variable coefficients that do not change with time (Blundell and Bond, 1998). This can be represented as follows:

\[ y_{it} = \alpha_0 + \alpha_1 y_{i,t-1} + \beta ee_{sca_{it-1}} + yX_{it} + \mu_i + \lambda_t + \epsilon_{it} \]  

(3)

where \( y_{it} \) represents the industrial pollution emissions of each sample city (including industrial SO\(_2\), industrial waste water, and industrial soot and dust). \( y_{i,t-1} \) is the lagged term of the pollution emissions, \( ee_{sca_{it-1}} \) is the local environmental protection expenditure, and \( X_{it} \) represents other control variables that influence industrial pollution, including per capita GDP (\( pgdp_{it} \)) and its square term (\( pgdp_{it}^2 \)), industrial structure (\( indus_{gdp_{it}} \)), foreign direct investment (\( fdi_{gdp_{it}} \)), economic openness (\( import_{exp}_{gdp_{it}} \)), and population density (\( pop_{den_{it}} \)), among others. These terms will be described in greater detail in Section 2.4. The variable \( \mu_i \) represents the unobservable city fixed effect and \( \lambda_t \) represents the year fixed effect. \( \epsilon_{it} \) is a random disturbance term (it obeys normal distribution), and \( u_i \) is uncorrelated with \( \epsilon_{it} \); \( i \), \( t \) represents the city and year, respectively.

### 2.3. Spatial panel model

Spatial autocorrelation refers to the interdependent relationship between the values of some variables in a certain region, which are manifested as similar observed values in regions with similar locations. The occurrence of spatial autocorrelation is the basis for using the Spatial Panel model. In order to accurately judge whether there is spatial autocorrelation of industrial pollution in China, Moran’s Index (Moran, 1950) and its scatter plot are used; the equation is presented as follows:

\[ Moran’s\ J = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} (X_i - \bar{X})(X_j - \bar{X})}{S^2 \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}} \]  

(4)

where \( \bar{X} = \frac{1}{S} \sum_{i=1}^{n} X_i \) and \( S^2 = \frac{1}{S} \sum_{i=1}^{n} (X_i - \bar{X})^2 \) are the mean and variance of samples, respectively; \( a_{ij} \) is the element in the spatial weight matrix used to measure the distance between region \( i \) and region \( j \); \( \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} \) is the sum of all weights.

The externality of public policies further intensifies the spatial correlation of environmental pollution (Maddison, 2006; Poon et al., 2006). Therefore, drawing on the work of Murdoch et al. (1997) and Fingleton and Szumilo (2019), the Spatial Panel model is used to explore the environmental governance effects of local environmental protection expenditure. The general form of the model is as follows:

\[ y_{it} = \beta_0 + \rho Wy_{it} + \beta_1 ee_{sca_{it}} + \beta_2 X_{it} + \theta_1 Wee_{sca_{it}} + \theta_2 WX_{it} + \mu_i + \lambda_t + \epsilon_{it} \]  

(5)

where \( y_{it} \) is the explained variable; \( ee_{sca_{it}} \) and \( X_{it} \) represent the environmental protection expenditure and control variables, respectively; \( \beta_1, \beta_2, \theta_1, \) and \( \theta_2 \) are the variable coefficients; \( W \) is the spatial weight matrix; \( \mu_i \) and \( \lambda_t \) represent city fixed effect and year fixed effect, respectively. When \( \theta_1 = \theta_2 = 0 \), the model is considered a Spatial Auto Regressive (SAR) model, otherwise it is an Spatial Durbin Model (SDM). In addition, due to the endogeneity of the spatial panel model, ordinary least squares regression is likely to lead to biased estimation coefficients. Therefore, the Maximum Likelihood (ML) method was used to estimate the Spatial Panel model in this paper to effectively overcome the estimation bias caused by endogeneity (Blonigen et al., 2007).

### 2.4. Variable description and data description

#### 2.4.1. Variable description

The explanatory variable of this study is industrial pollution emission (\( y_{it} \)), and the main pollutants include industrial SO\(_2\), industrial waste water and industrial soot and dust. The discharge of industrial solid waste is relatively low, and the National Bureau of statistics has not published the statistical data in 2016. Therefore, we will not discuss it here. The core explanatory variable is local environmental protection expenditure (\( ee_{sca_{it}} \)), which is the most effective and direct special expenditure by local governments in environmental governance in China. To alleviate the possible lag time effects of local government in environmental governance, the lagging item of environmental protection expenditure is added into the model. The relevant control variables include per capita real GDP (\( pgdp_{it} \)) and its square term (\( pgdp_{it}^2 \)), which are used to test the “Environmental Kuznets” hypothesis; namely, whether environmental pollution first increases and then decreases with economic growth (Grossman and Krueger, 1991). Many studies examine the relationship between economic development and environmental quality by testing this hypothesis (Chen et al., 2020; Egbeiokun et al., 2020; Kwakwa, 2021). Per capita real GDP was converted according to the GDP index in 2007. Industrial structure (\( indus_{gdp_{it}} \)) is expressed by the proportion of the value of the secondary industry in the city’s GDP. Economic openness (\( fdi_{gdp_{it}} \) and \( import_{exp}_{gdp_{it}} \)) is expressed as the proportion of foreign direct investment (FDI) and total imports and exports to the region’s GDP. Population density (\( pop_{den_{it}} \)) is expressed by the number of people in each city divided by the city area.

#### 2.4.2. Data description

The research focus of this paper is 286 prefecture-level cities in China. Taiwan, Hong Kong, Macao, and a few other cities are excluded due to lack of data. It is difficult to determine the total amount of fiscal expenditure on environmental protection in the cities before 2007 because it is scattered among other kinds of expenditure, and since many cities lack data for 2018. Therefore, the study period was selected to run from 2007 to 2017. Whereas central government expenditure on environmental protection goes not only to pollution control but also to renewable energy use, conversion of farmland to forests, desertification prevention and control, and local government expenditure on environmental protection is mainly used for pollution prevention and control. Table 1 gives the measurement methods and data sources of relevant variables. Descriptive statistics of relevant variables are shown in Table 2.

### 3. Results and discussion

#### 3.1. Emission characteristics of industrial pollution in China

Appendix Table 1 presents the overall emission characteristics of major industrial pollutants in China from 2007 to 2017. Among them, industrial SO\(_2\) emissions showed a slowly declining trend but remained at a high level from 2007 to 2015; additionally, levels rebounded in 2011, reaching 18.46 million tons, and began to decline significantly after 2015. Industrial soot and dust discharge increased continuously from 2007 to 2014; they reached a peak of 12.48 million tons in 2014 after 2015. Industrial soot and dust discharge increased continuously at a high level from 2007 to 2015; additionally, levels rebounded in 2011, reaching 18.46 million tons, and began to decline significantly after 2015. Industrial soot and dust discharge increased continuously from 2007 to 2014; they reached a peak of 12.48 million tons in 2014 after 2015. Industrial soot and dust discharge increased continuously from 2007 to 2014; they reached a peak of 12.48 million tons in 2014 after 2015. Industrial soot and dust discharge increased continuously from 2007 to 2014; they reached a peak of 12.48 million tons in 2014 after 2015.
industrial waste water are still the key emphasis of China’s current industrial pollution control measures.

The distribution characteristics of industrial pollution emissions in various regions of China (Fig. 1) show that: (1) the main industrial pollutant emissions of various provinces and cities have obvious spatial spillovers. Among them, industrial SO2 emissions are mainly centered in Shandong, Henan, Hebei, and Shanxi, and gradually spread to neighboring regions such as Inner Mongolia, Jiangsu, and Liaoning. Industrial soot and dust discharges are mainly concentrated in Shanxi, Henan, Hebei, and Liaoning, and gradually spread to neighboring places such as Heilongjiang, Shandong, Inner Mongolia, and Jiangsu. The comparison reveals that the spillover regions of industrial SO2 and soot and dust are relatively similar, while industrial waste water discharges are different; the latter are mainly concentrated in coastal regions such as Jiangsu, Zhejiang, Shandong, Guangdong, and Fujian, and gradually spread to Anhui, Jiangxi, Hubei, Hunan, and other inland regions. (2) There are some regional differences in the discharge of major industrial pollutants. For example, in northern China, where industrial SO2 and soot and dust discharges are concentrated, pollution emissions in Beijing and Tianjin are relatively low. This contrasts with western regions where pollution emissions are generally low, but pollution emissions in Sichuan, Inner Mongolia, and Guangxi are generally high. (3) Compared with the base period (2007), although the pollution discharge in the reporting period declined (2017), the results show the characteristics of time duration, i.e., most of the provinces and cities with heavier emissions in the base period have a higher discharge during the reporting period, thereby showing strong path dependence.

The Covid-19 pandemic has severely affected China as well as the global economy. Under the influence of the pandemic within China, the characteristics of unbalanced and inadequate development have become more prominent, and energy consumption and pollution emissions between regions have become highly differentiated (Song et al., 2020a). To a certain extent, the difference in emissions between cities reflects the gap in the social and economic development of these cities. The government’s emission reduction requirements for different cities influence the development rights and moral responsibilities of these cities (Wang et al., 2015). In addition, in view of the public goods attributes and the strong positive externalities of pollution control, the excessive difference in pollution emissions between cities also restricts the coordinated development of the social economy and the ecological environment (Zheng et al., 2015). Differences in socio-economic endowments, such as GDP and population size may have strong path dependence and are difficult to adjust in a short time. In China, the imbalance of social and economic endowments such as the level of economic development, population size, and industrial structure has largely contributed to the differences in pollution emissions among the country’s regions, especially between cities. It is difficult to highlight the effects of policy control on industrial pollution emissions from geographic or administrative regions to study the impact of local fiscal expenditure on industrial pollution; it is also not conducive to the refinement and implementation of government pollution reduction policies (Cheng et al., 2021b). Consequently, cities with similar socio-economic endowments were clustered through HCA, and then the pollution emission characteristics within and between clustering cities were discussed. This lays a solid foundation for further exploration of the environmental governance effects of local environmental protection expenditure.

Appendix Table 2 gives descriptive statistics of social and economic indicators, such as GDP, the value of the secondary industry, foreign investment, total imports and exports, and population size of each clustering city group from 2007 to 2017. The results show that the eastern coastal cities, provincial capital cities, and regional central cities are the main cities in Cluster 1; their various social and economic indicators are far higher than those in Clusters 2 and 3. The main reason is that the imbalance of the social and economic endowments of each clustering city group is not only limited by the region but also related to China’s early implementation of a development strategy that preferentially developed its eastern regions first. In the early stage of China’s reform, domestic capital, technology, and human capital were relatively scarce.效率 was the basic guiding ideology of the central government, and they implemented a gradient development strategy where they pooled funds and resources towards the development of coastal regions and pillar industries. The underdeveloped regions fell into the Matthew effect; such a vicious cycle has led to an ever-widening development gap between different regions (Kenneth Keng, 2006).

Due to the obvious spatial spillover of major industrial pollutants, the role of geographic features when analyzing the impact of local environmental protection expenditure on industrial pollution cannot be ignored. On the one hand, the spatial distribution characteristics of pollution emissions themselves are affected by geographic correlation; additionally, there are differences in geographic and climatic conditions,
Fig. 1. Distribution of industrial pollution emissions.

Notes: (1) Considering the availability and consistency of the data, the emission data of all provinces are aggregated based on city data. (2) The industrial SO$_2$ emissions, industrial soot and dust discharges, and industrial waste water discharges are sourced from the China City Statistical Yearbook. (3) 2007 and 2017 are the base period and the report period, respectively.
such as altitude, air pressure, temperature, and humidity. As a result, the spread of air and water pollution in the region presents different characteristics (Masters and Ela, 2007). In addition, the geographic location characteristics of each region will affect the FDI, the openness of the region, and other indicators; it will also indirectly affect the pollution emissions of each region. On the other hand, when local governments use fiscal expenditure to improve the environment quality, they will also consider the impacts of geographical relevance. Neighboring local governments may imitate each other in terms of their environmental policies. Given the spatial spillover of pollutant emissions, the environmental regulations of one region not only act on the local environment quality, but also affect the environment quality of neighboring regions. Meanwhile, the environmental regulations of neighboring local governments will indirectly affect the environmental quality of their own regions. However, this effect will be attenuated with the expansion of geographical distance (Anderson, 2012). Based on this, this paper refers to the practice of Stakhovych and Bijnovt (2009), and Harris et al. (2011). In this paper, the Inverse-distance Based Spatial Weights Matrix is introduced into the spatial econometric model to analyze the impact of local fiscal expenditure on industrial pollution emissions in China.

Appendix Table 3 shows Moran’s I and test results for industrial pollution. The results showed as follows: (1) from 2007 to 2017, the Moran’s I value of various pollutants were all between 0.025 and 0.123 and were significant at the 1% significance level; this indicated that various industrial pollutants were correlated with geographical distance in recent years. (2) There are certain differences in the variation trends of the Moran’s I of various pollutants. Among them, the Moran’s I of industrial waste water discharges shows a gradually increasing trend, the Moran’s I of industrial SO_2 first increased and then decreased, and the Moran’s I of industrial soot and dust shows a general downward trend.

To further understand the spatial distribution characteristics of the three target pollutant emissions, the Moran’s I scatter plots of different industrial pollutant emissions in different cities in the base period and the reporting period are drawn, as shown in Fig. 2. The results show that the sample cities of various pollutants are mainly scattered in the first and third quadrants, showing obvious high-high clustering, and low-low clustering; that is, the results depict positive spatial correlation. This indicates that the industrial pollution in the vicinity of the cities with higher industrial pollution is also higher than the mean value, and vice versa; the industrial pollution in the vicinity of the cities with lower industrial pollution is also lower than the mean value. This is consistent with the view of Yang et al. (2021), who also found that environmental pollution in various regions of China had significant positive spatial autocorrelations.

The measurement of Moran’s I can prematurely determine that there is a certain correlation between industrial pollution and geographical distance. Therefore, the inverse distance matrix is introduced into the spatial SDM model and spatial SAR model to further assess the effects of local fiscal expenditure on industrial pollution emissions. To ensure the standardization of the influence of other cities on a specified city, the spatial weight matrix is standardized so that all weights are between 0 and 1.

3.2. Environmental governance effects of local environmental protection expenditure

3.2.1. Impact of local environmental protection expenditure on industrial pollution

Table 3 shows the impact of local environmental protection expenditure on industrial pollution in China. Columns (1), (3), and (5) only control the city fixed effect, while columns (2), (4), and (6) control the bidirectional fixed effect of city and year. As seen from the results, first, the coefficients of all explained variables lagging one period were significantly positive at the 1% level, and the coefficient values were large, ranging from 0.644 to 0.862. This also confirmed the existence of time duration of various pollutants from the econometric regression; that is, the pollution of the previous period did significantly impact the current pollution. Secondly, the impacts of local environmental protection expenditure on the emissions of all kinds of pollutants were significantly negative; this indicates that increasing local environmental protection expenditure can help to reduce pollution emissions, which is consistent with the findings of Huang (2021). Finally, after controlling for the time fixed effect, all types of pollutants met the “Environmental Kuznets” hypothesis; with economic growth, the emissions of all types of pollutants showed a process of first increased and then decreased quantities (Shahbaz et al., 2018).

The above results show that China’s local environmental protection expenditure can significantly reduce industrial pollution emissions, thereby improving environmental quality. There are two main reasons: first, environmental protection expenditure as the most effective mean of environmental governance by local government can be directly used for local pollution prevention and control in ways such as ecological protection, environmental monitoring, preventing wind and sand erosion, renewable energy utilization, and returning farmland to forests, so as to have a direct improvement effect on environmental quality. Second, as an input-based environmental regulation method for local governments, environmental protection expenditure can reflect the government’s attention to environmental governance and has policy orientation and regulation orientation. Its policy orientation can guide social capital to prefer environmental investment, thereby adjusting the industrial structure of the region and indirectly promoting energy

Table 3: Impact of environmental protection expenditure on industrial pollution.

|               | SO_2         | Waste water | Soot and dust |
|---------------|--------------|-------------|---------------|
|               | (1)          | (2)         | (3)           | (4)           | (5)           | (6)           |
| $\xi_{t-1}$  | 0.752*** (0.015) | 0.776*** (0.013) | 0.862*** (0.006) | 0.840*** (0.007) | 0.644*** (0.012) | 0.706*** (0.007) |
| $\epsilon_{t-1}$ | -0.302** (0.063) | -0.362*** (0.045) | -0.198*** (0.053) | -0.158*** (0.030) | -0.159*** (0.051) | -0.056** (0.024) |
| Environmental Kuznets | NO            | YES         | NO             | YES           | YES           | YES           |
| Control variables | YES         | YES         | YES            | YES           | YES           | YES           |
| City fixed effect | YES         | YES         | YES            | YES           | YES           | YES           |
| Year fixed effect | NO          | YES         | NO             | YES           | NO            | YES           |
| AR (1) P-value | 0.007        | 0.014       | 0.020          | 0.022         | 0.000         | 0.000         |
| AR (2) P-value | 0.066        | 0.101       | 0.262          | 0.256         | 0.416         | 0.941         |
| Sargan test    | 126.126      | 107.564     | 88.581         | 79.550        | 108.599       | 115.501       |
| Observations   | 2860         | 2860        | 2860           | 2860          | 2860          | 2860          |

Notes: (1) ***, ** and * represent significance levels of 1%, 5% and 10%, respectively, and the values in the parentheses are the robust standard errors of the estimated coefficients. The above notes are consistent in Table 4–7. (2) The Sargan test gives the value of chi^2. This note is consistent in Table 4–5. (3) The Environmental Kuznets hypothesis is verified by per capita GDP and the per capita GDP squared term. When the coefficient of per capita GDP is significantly positive and the coefficient of the per capita GDP squared term is significantly negative, the Environmental Kuznets hypothesis is satisfied. (4) In order to ensure the consistency of results and simplify the table, regression results of all control variables are not presented. Subsequent tables are similarly designed and will not be repeated.
Fig. 2. Moran’s Index scatter plot of industrial pollution.
Notes: (1) Moran’s I scatter plot is a two-dimensional distribution of sample observations and their spatial lag terms. (2) The slope of the red line is Moran’s Index. (a) and (b) represent industrial SO$_2$ emissions in 2007 and 2017, respectively; (c) and (d) represent industrial waste water discharges in 2007 and 2017, respectively; (e) and (f) represent industrial soot and dust discharges in 2007 and 2017, respectively.
conservation and emission reduction, achieving the improvement of environmental quality. Its regulatory orientation of environmental protection expenditure can not only indirectly force industrial enterprises to raise environmental standards, but can also continuously improve technological innovation and achieve cleaner production (Song et al., 2020b), ultimately reducing pollution emissions.

3.2.2. Robustness test

A series of robustness tests, such as changing the lag order of various expenditure scales, dealing with the most extreme 5% of the sample, and replacing industrial pollutant emission with annual emission reduction, were also performed to verify the validity of the baseline regression results (Table 4). In columns (1), (4), and (7), given that the effects of local environmental protection expenditure on industrial pollution have a certain lag effect, current expenditure is likely to have an effect in the results (Table 4). In columns (1), (4), and (7), given that the effects of emission reductions in the current period, the fewer emissions in the subsequent period.

3.3. Further research on the environmental governance effects of local environmental protection expenditure

3.3.1. Analysis of regional differences

Table 5 shows the influence of local environmental protection expenditure on industrial pollution in each clustering city group. For Cluster 1, the environmental protection expenditure is significantly negative for all kinds of industrial pollutants at the significance level of 1%; which means that the increase in local environmental protection expenditure helps to reduce the emissions of all kinds of industrial pollutants. Except for industrial soot and dust, the emissions of

Table 5

Impact of environmental protection expenditure on industrial pollution in each clustering city group.

| Cluster | \( x_{1-1} \) | \( x_{1-1} \) | \( x_{1-1} \) | \( x_{1-1} \) | \( x_{1-1} \) | \( x_{1-1} \) | \( x_{1-1} \) |
|---------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1       | 0.739***      | 0.818***      | 0.806***      |              |              |              |              |
|         | (0.005)       | (0.006)       | (0.004)       |              |              |              |              |
| 2       | 0.074***      | 0.097***      | 0.021***      |              |              |              |              |
|         | (0.027)       | (0.021)       | (0.008)       |              |              |              |              |
| 3       | 0.179***      | 0.357***      | 0.446***      |              |              |              |              |
|         | (0.016)       | (0.107)       | (0.257)       |              |              |              |              |

Note: The observed value in Clusters 1 and 2 is 950, and the observation value in Cluster 3 is 960.

Table 4

Robustness test of the environmental protection expenditure effect.

| Control variables | SO\(_2\) | Waste water | Soot and dust |
|-------------------|---------|-------------|---------------|
|                   | (1)     | (2)         | (3)           |
|                   | (4)     | (5)         | (6)           |
|                   | (7)     | (8)         | (9)           |
| \( y_{1-1} \)     | 0.773***| 0.933***    | -0.262***     |
|                   | (0.012) | (0.018)     | (0.007)       |
| \( ee_{SO_2} \)   | -0.303***| -0.046***  | -0.327***     |
|                   | (0.038) | (0.020)     | (0.040)       |
| Control variables | YES     | YES         | YES           |
| City fixed effects| YES     | YES         | YES           |
| Year fixed effect | YES     | YES         | YES           |
| AR (1) P-value    | 0.014   | 0.000       | 0.013         |
| AR (2) P-value    | 0.100   | 0.243       | 0.193         |
| Observations      | 2860    | 2860        | 2574          |

Notes: The emission reduction in columns (3) is the difference between the current pollutant emissions and the previous pollutant emissions; therefore, all the sample sizes of the base period will be lost, and the observed value becomes 2574. In addition, the coefficients of the pollution lag term in columns (3), (6), and (9) are negative, indicating that the more emission reductions in the current period, the fewer emissions in the subsequent period.
industrial SO$_2$ and industrial waste water meet the “Environmental Kuznets” hypothesis; that is, with the economic growth of Chinese cities, the emissions of these pollutants are likely to increase at first, and then decrease. The lag terms of all kinds of pollutants are significantly positive at the 1% significance level, and the coefficient values are large, ranging between 0.739 and 0.981; this indicates that the time duration of all kinds of pollutants also exists in Cluster 1. For Cluster 2, the environmental protection expenditure is significantly negative for all kinds of industrial pollutants at the significance level of 1%. Except for industrial soot and dust, all kinds of pollutants do not satisfy the “Environmental Kuznets” hypothesis. The lag terms of all kinds of pollutants are significantly positive at the 1% significance level, and the coefficient values are large, ranging between 0.441 and 0.978, which indicates that the time duration of all kinds of pollutants also exists in Cluster 2. For Cluster 3, the environmental protection expenditure is significantly positive for all kinds of industrial pollutants at the significance level of 1%; this means that the environmental protection expenditure not only does not have an inhibiting effect on all kinds of pollutants in Cluster 3 but that it even brings about their increase. All industrial pollutants satisfy the “Environmental Kuznets” hypothesis for Cluster 3. The lag terms of all kinds of pollutants are significantly positive at the 1% significance level for Cluster 3, and the coefficient values are large, ranging between 0.513 and 0.848, which indicates that the time duration of all kinds of pollutants also exists in Cluster 3.

3.3.2. Analysis of spatial spillover

Table 6 shows the spatial regression results of the impact of environmental protection expenditure on China’s industrial pollution. After controlling the city fixed effects and the year fixed effects, the spatial regression results of environmental protection expenditure on the emissions of various pollutants are found to be quite different. The results of the SDM model revealed that the local effects of environmental protection expenditure on industrial SO$_2$ and industrial waste water are both significantly negative at the 1% significance level, meaning that the increase in environmental protection expenditure of local governments will help to reduce local industrial pollutant emissions and improve the quality of the environment. However, the neighborhood effect is different. Among them, the neighborhood effect of environmental protection expenditure on industrial SO$_2$ is the most significant, followed by industrial waste water. This shows that the cross-regional governance effect of local environmental protection expenditure on highly mobile pollutants such as industrial SO$_2$ is more effective. Except for industrial waste water, the spatial lag coefficients of various pollutants are relatively large, which are statistically significantly positive at the 1% significance level, which indicates that industrial pollution in neighboring cities will affect the environmental quality of the city to a certain extent. In other words, the spillover of industrial pollution in various cities exists. The results of the SAR model revealed that the local effects of environmental protection expenditure on industrial SO$_2$ and industrial waste water are both significantly negative at the 1% significance level. Except for industrial waste water, the spatial lag coefficients of various pollutants are relatively large, and statistically they are equally significant and positive at the 1% significance level. Comparing the results of the SDM and SAR models, the main conclusions are similar, which further confirms the robustness of the results.

Through the application of the SDM and SAR models, this paper spatially verifies the effects of local environmental expenditure on industrial pollution in China. The primary conclusions elucidated by both models are consistent with one another, which further confirm the robustness of the results. However, the data generation process of these two types of models is nonlinear, and the coefficients of local effect and neighborhood effect in Table 6 cannot fully reflect the impact of environmental expenditure on various types of pollution emissions. To give a more accurate interpretation of the direct effect of a city’s environmental protection expenditure on local pollution levels, the indirect effect on the pollution levels of a nearby city (or spillover effect), as well as the total effect, this section calculates the direct, indirect, and total effect of local environmental protection expenditure on industrial pollution based on the research of Lesage and Pace (2009).

As shown in Table 7, the results showed that: both the SDM and SAR models revealed that the direct effect of environmental protection expenditure on industrial SO$_2$ of the city, the indirect effect on industrial SO$_2$ of the neighboring cities, and the total effect were significantly negative, and the indirect effect was far greater than the direct effect. Additionally, in terms of the indirect and total effect of the two models, the SAR model with local effect of environmental protection expenditure is significantly lower than the SDM model containing both local and neighborhood effect; this proves that the neighborhood effect plays an important role in local government environmental governance. This conclusion is similar to the research conclusion of Yang (2021), who found that the environmental protection expenditure of local governments had a significant impact on the improvement of the ecological environment in the surrounding regions. Notably, compared with other pollutants, industrial SO$_2$ has stronger spatial mobility and diffusion; therefore, the trans-regional governance effect of local environmental protection expenditure is more effective for such pollutants.

The above results indicate that the environmental governance effects of local environmental expenditure are not only reflected in the local

### Table 6

|                | SO$_2$ | Waste water | Soot and dust |
|----------------|--------|-------------|---------------|
| SDM Local effect | -0.343*** | -0.292*** | -0.000 |
|                | (0.04) | (0.068) | (0.036) |
| Neighborhood effect | -1.798*** | -1.733* | 2.036*** |
|                | (0.669) | (1.032) | (0.540) |
| Spatial lag term | 0.605*** | -0.082 (0.138) | 0.673*** |
|                | (0.088) | (0.077) | |
| $r^2$          | 0.190 | 0.005 | 0.010 |
| ML value       | -6807.707 | 8479.584 | 6455.832 |
| SAR Local effect | -0.357*** | -0.244*** | 0.013 (0.036) |
|                | (0.040) | (0.069) | |
| Spatial lag term | 0.673** | 0.338** | 0.720*** |
|                | (0.077) | (0.111) | (0.068) |
| $r^2$          | 0.302 | 0.096 | 0.015 |
| ML value       | -6828.799 | 8522.061 | 6467.999 |

**Control variables**

|                | YES | YES | YES |
|----------------|-----|-----|-----|
| City fixed effect | YES | YES | YES |
| Year fixed effect | YES | YES | YES |
| Observations    | 3146 | 3146 | 3146 |

Note: The SAR model itself does not include the spatial weight item of expenditure scale, so it cannot show the neighborhood effect.

### Table 7

|                | SO$_2$ | Waste water | Soot and dust |
|----------------|--------|-------------|---------------|
| SDM Direct effect | -0.362*** | -0.288*** | 0.027 (0.037) |
|                | (0.042) | (0.071) | |
| Indirect effect | -5.290*** | -1.624* (0.938) | 6.356*** |
|                | (1.965) | (2.321) | |
| Total effect    | -5.653*** | -1.912** | 6.383*** |
|                | (1.973) | (2.228) | |
| SAR Direct effect | -0.359*** | -0.242*** | 0.014 (0.037) |
|                | (0.041) | (0.071) | |
| Indirect effect | -0.783** | -0.132* (0.078) | 0.037 (0.106) |
|                | (0.307) | (2.321) | |
| Total effect    | -1.412*** | -0.374*** | 0.051 (0.141) |
|                | (0.322) | (0.128) | |

**Control variables**

|                | YES | YES | YES |
|----------------|-----|-----|-----|
| City fixed effect | YES | YES | YES |
| Year fixed effect | YES | YES | YES |
| Observations    | 3146 | 3146 | 3146 |
pollutants but also in neighboring regions. That is, the fiscal expenditure policy in the neighboring regions will have a significant spillover impact on the environmental pollution in the region. Moreover, the stronger the spatial mobility and diffusion of pollutants, the more effective the trans-regional governance effect of the local fiscal expenditure structure is likely to be. There may be two reasons for this: first, according to the externality theory, environmental pollution has a strong negative externality, especially for pollutants with strong spillage, such as waste water and waste gas, which cannot clearly identify their property rights by themselves and are difficult to be addressed by the market. Such pollutants show up as a market failure, and it may be more effective for the government to control them. Second, according to public finance theory, at present, the provision of environmental public goods in China mainly comes from government departments, especially local governments. However, there are positive externalities in environmental governance by local governments, especially for pollutants with strong spillover, and the cross-regional governance effect is more significant. Therefore, a joint prevention and control mechanism of “joint prevention and control and cross-regional governance” must be established. Otherwise, the “free rider” phenomenon in neighboring regions, which exists in environmental governance (Yang, 2021), will cause local re-spillover, and the cross-regional governance effect is more significant. There may be two reasons for this: first, according to the situation of local pollution emissions, and an
direct effect of environmental protection expenditure on high spillover
fundamentals, especially for pollutants with strong spillage, such as waste
water and waste gas, which cannot clearly identify their property rights
by themselves and are difficult to be addressed by the market. Such
pollutants show up as a market failure, and it may be more effective
for the government to control them. Second, according to public finance
theory, at present, the provision of environmental public goods in China
mainly comes from government departments, especially local govern-
ments. However, there are positive externalities in environmental
governance by local governments, especially for pollutants with strong
spillover, and the cross-regional governance effect is more significant.
Therefore, a joint prevention and control mechanism of “central unified
deployment and local cross-border governance” must be established.
Otherwise, the “free rider” phenomenon in neighboring regions, which
exists in environmental governance (Yang, 2021), will cause local re-

governance leads to the loss of overall governance efficiency. Therefore,
local governments at all levels, in combination with the actual situation
of their regions, should refine relevant laws and regulations, and build a
multi-level government cooperation mechanism composed of three
arms: a decision-making, coordination, and implementation arm. The
information technology methods of the new era such as big data, cloud
computing, and artificial intelligence can accurately grasp not only the
emission situation, but also the distribution characteristics, temporal
and spatial changes, and diffusion laws of environmental pollution in
various regions. This information should be effectively utilized to clarify
responsibilities and to develop differentiated and refined regional joint
prevention and control plans.

4. Conclusions and policy implications

Based on the data of 286 prefecture-level cities in China from 2007 to
2017, this study investigated the effects of local environmental protec-
tion expenditure on China’s industrial pollution on the basis of full
consideration of the time duration, regional differences, and spatial
spillover of pollution emissions. Through HCA, the environmental
governance effects within and between clustering city groups could be
explained. The findings have important reference significance for China
towards improving environmental quality, reducing fossil energy de-
mand, and maintaining energy security in the post Covid-19 era. The
main conclusions are as follows: (1) local environmental expenditure
helps to reduce industrial pollution emissions in Chinese cities; addi-
tionally, the time duration of various pollutants and the “Environmental
Kuznets” hypothesis (Song et al., 2008) have been verified. (2) The
environmental governance effects of environmental protection expendi-
ture are heterogeneous in different clustering city groups. Among
them, the effect was significantly negative in Clusters 1 and 2, which
have more developed socio-economic conditions, while it was signifi-
cantly positive in Cluster 3, which has a less developed economy. (3)
Local environmental protection expenditures have played a positive role
in the treatment of local industrial pollution. However, the neighbor-
hood effects of environmental protection expenditures on different
pollutants are quite different, showing that the stronger the spillover
of pollutants, the more significant the effect of local environmental pro-
tection expenditures on cross-regional governance. (4) Finally, the in-
direct effect of environmental protection expenditure on high spillover
pollutants is significantly greater than the direct effect.

In view of the above conclusions, several implications are apparent.
First, local governments should take more responsibility for environ-
mental governance and improve the efficiency of environmental pro-
tection expenditure. As an important means of environmental governance, local environmental expenditure should play a guiding role.
For example, local governments can use fiscal subsidies, green procu-
rement, and investment in pollution control to guide enterprises not
only towards achieving cleaner production, but also in actively reducing
emissions and fully mobilizing the initiative of all sectors of society in
pollution prevention and control. Further, local governments can use
this approach in providing fiscal policy support to accelerate the con-
struction of a greater resource-saving and environment-friendly society.
Environmental protection expenditure should be appropriately posi-
tioned according to the situation of local pollution emissions, and an
effective management mechanism should be realized according to local
conditions. Doing so will improve the matching degree and governance
efficiency of local environmental protection expenditure.

Second, local governments should support the cooperation model of
“joint prevention and control and cross-regional governance” when
dealing with pollutants with high spillover potential. The fundamental
purpose of cross-regional cooperative governance is to solve the problem
that local governments’ realization of optimal local environmental
governance leads to the loss of overall governance efficiency. Therefore,
local governments at all levels, in combination with the actual situation
of their regions, should refine relevant laws and regulations, and build a
multi-level government cooperation mechanism composed of three
arms: a decision-making, coordination, and implementation arm. The
information technology methods of the new era such as big data, cloud
computing, and artificial intelligence can accurately grasp not only the
emission situation, but also the distribution characteristics, temporal
and spatial changes, and diffusion laws of environmental pollution in
various regions. This information should be effectively utilized to clarify
responsibilities and to develop differentiated and refined regional joint
prevention and control plans.

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Declaration of competing interest

There is no conflict of interest.

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Appendix A. Supplementary data

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negative in Clusters 1 and 2, which have more developed socio-economic conditions, while it was significantly positive in Cluster 3, which has a less developed economy. (3) Local environmental protection expenditures have played a positive role in the treatment of local industrial pollution. However, the neighborhood effects of environmental protection expenditures on different pollutants are quite different, showing that the stronger the spillover of pollutants, the more significant the effect of local environmental protection expenditures on cross-regional governance. (4) Finally, the indirect effect of environmental protection expenditure on high spillover pollutants is significantly greater than the direct effect.
