RESEARCH ARTICLE

A study of the influence of regional environmental expenditure on air quality in China: the effectiveness of environmental policy

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Abstract

Based on the panel data model, data on environmental expenditures, the air quality index, economic aggregates, industrial structures, etc., of seven seriously polluted cities in China, from the period 2007–2015, were collected, and this paper estimates the general relationship between environmental expenditures and the air quality index. Besides, the impact of the fuel tax policy on air quality as well as on the relationship between environmental expenditure and the air quality index is tested using the method of regression discontinuity. We find that there is a long-term equilibrium relationship between environmental expenditure and air quality index as well as a 0.0507% positive effect of the former on the latter. Second, for Beijing, Taiyuan, Chongqing, and Lanzhou, a 1% increase in environmental expenditure leads to 0.0773, 0.0125, 0.0965, and 0.0912% decreases in the air quality index, respectively; however, for Shijiazhuang, Ji'nan, and Urumqi, effect of environmental expenditure on air quality is insignificant. Third, both economic growth and optimization of the industrial structure can lead to an improvement of air quality. Fourth, since the implementation of the fuel tax policy in 2009, the air quality of the sample cities has improved, and the pulling effect of environmental expenditure on the air quality index has decreased from 0.0507 to 0.0048%. Our findings cannot only clarify the effect of environmental expenditures on air quality but can also objectively judge the effectiveness of environmental policies of China to a certain extent. It may benefit Chinese government to effectively govern air pollution with fiscal tools in conjunction with economic and environmental characteristics.

Introduction

Because air pollution gradually transforms into combined pollution, particular phenomena, such as PM2.5 and O_3 pollution, frequent haze, and reduced visibility, are highlighted. According to the statistics of the World Health Organization (WHO), there were 1.34 million people who died of outdoor air pollution worldwide in 2008. In 2012, approximately 7 million people died of air pollution. Environmental security has become an important guarantee for people's lives. Under

the background of the new normal economy, the carrying capacity of resources and the environment in China has reached or approached the upper limit. According to the environmental performance ranking of 180 countries in the "Environmental Performance Index: 2016 Report," China ranks next to last. In addition, "China's environmental status bulletin 2015" shows that among the 338 cities at the prefecture level and above in China, more than 78.4% of the ambient air quality of these cities exceeds the standard. Under this background, society should put forward higher requirements for environmental protection and environmental monitoring. In theory, the public goods of environmental dictates established by the government should provide a good environment and protect the environment. Therefore, control of environmental pollution has become an important problem that urgently needs to be solved by the government and society. Moreover, the Third Plenary Session of the 18th CPC Central Committee noted that public finance is an important pillar and source of funds for state governance, and the

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department of the treasury plays an important role in environmental pollution control (Wu et al. 2012). From a practical point of view, Chinese environmental expenditures increased from 995.582 to 4802.89 billion yuan, with an average annual growth of 21.73% during 2007–2015. Although the absolute amount of China's energy-savings and environmental expenditures increased year by year, environmental problems, especially regarding air quality, are still deteriorating. Therefore, it is necessary to objectively study the relationship between environmental expenditures and air quality.

As for environmental expenditures, Yuan and Kong (2015) explained the relationship between environmental investment and fiscal environmental expenditures. They noted that the caliber of the statistics of local environmental investment contains the vast majority of local fiscal expenditure; only the recurring expenditure that accounts for a small proportion of public expenditure on environmental protection is not included. However, investment in the control of environmental pollution is relatively independent from local public environmental expenditure because the majority of sources of pollution control funds come from the self-financing of individual enterprises, and the rest are the form of subsidies that are returned to the enterprises in the form of sewage charges. Therefore, this paper studies the relationship between fiscal expenditures and air quality in the long term from a macro perspective and then analyzes the effectiveness of environmental protection policy from the perspective of the promotion effects of fiscal and taxation tools on air pollution control. Section 2 of this paper is a review of the literature. Section 3 analyzes the mechanisms by which environmental expenditures affect air quality. Section 4 describes models and variables. Section 5 presents empirical research and a robustness analysis based on the panel data of seven heavily polluted cities in China. Conclusions are given in Section 6.

Review of the literature

From the research perspective, a large number of scholars have paid considerable attention to the relationships among environmental investment, economic growth, and air quality. The research can be divided into two aspects. The first aspect is research on the impact of environmental investment on economic growth. For example, by using a cointegration test, Liu (2012) concludes that there is long-term equilibrium between environmental investment and economic development in the eastern, central, and western regions of China. Zhu et al. (2014) draw the same conclusion and further note that when environmental investment increased by 1%, the GDP grew at a rate of 0.13%, which shows that environmental investment significantly affects the GDP. By taking the total environmental investment of the Silk Road Economic Belt as an example, Huang et al. (2016) proved that regional

environmental investment can effectively promote overall economic growth and optimization of the economic structure and employment levels. In addition, Zhang et al. (2012) notes that environmental investment is different from general investment: in addition to having a significant role in boosting economic growth, it also has a considerable technology spillover effect on economic development, which can promote technological progress and upgrades in enterprises. The second aspect requires research on the impact of economic growth on air quality. Antoci et al. (2007) hold that air quality can be improved by investing social capital in environmental products. Gao and Huang (2015) also affirm the positive effect of environmental investment on the reduction of industrial pollution. Furthermore, based on the endogenous growth model, Lin et al. (2012) take environmental quality into the utility function and prove that environmental investment can urge production technology to be more environmentally friendly as well as improve the level of environmental technology and then be used to achieve economically sustainable growth under the established environmental regulations. In addition, the study by Grossman and Krueger (1992) on the relationship between environmental quality and per capita income by using empirical analysis proposes that economic growth affects environment quality through the scale effect, technical effect, and structural effect channel. Panayotou (1993) defines this relationship as an environmental Kuznets curve (EKC). Chinese scholars mainly explore the applicability of an environmental Kuznets curve in China (Zhang et al. 2011; He and Du 2015).

On the relationship between environmental expenditure and air quality, most scholars pay attention to the mutual effect between fiscal policy and environmental pollution (quality), which can be summarized into two aspects. The first aspect is the perspective of the fiscal expenditure scale. Yu and Yang (2016) use a fixed effect model to examine the impact of the scale of local fiscal expenditures on environmental pollution. The result shows that the overall impact of the scale of local fiscal expenditures on China's environmental pollution is uncertain. The scale of local fiscal expenditure reduces environmental pollution through structural effects and substitution effects while improving environmental pollution through the growth effect. The second aspect is the perspective of the structure of fiscal expenditures. Based on the empirical model, López et al. (2011) analyze the impact of the mode of fiscal expenditures on the environment. They believe that the redistribution of government spending into the community and public goods can reduce pollution; however, simply increasing total government expenditures without changing their composition does not work. Lu et al. (2015) examine the influence of China's fiscal expenditure structure on consumption-oriented environmental pollution under different institutional surroundings and note that the increase of non-economic government expenditures would exacerbate

consumption-oriented environmental pollution when the consumption financing effect prevails. Conversely, consumption-oriented environmental pollution will be reduced when the environmental regulation effect dominates. Some scholars believe that the increase in the proportion of economic construction expenditures will aggravate China's environmental pollution, while increasing the proportion of social service expenditures is conducive to reducing environmental pollution (Yu and Yang 2016).

Further, other scholars mainly concentrate on analyzing the effect of environmental policy on comprehensive environmental administration and affirm the positive effect of the former on the latter (Almond et al. 2009; Gao et al. 2011; Wang 2011; Cao et al. 2014). The few direct studies on environmental policy and air quality are on the regional level and demonstrate that different policies have the otherness of the implementation effect in different regions (Cao et al. 2014; Qi et al. 2015; Xu et al. 2015). Based on these studies, this paper attempts to make further progress by including existing studies on environmental issues that mostly use industrial wastewater and exhaust gas (SO_2) emissions as substitution variables of environmental pollution as well as adopting the air quality index (pollution) to reflect environmental pollution. Second, with the panel data model, this paper uses seven cities in China, representing the most seriously polluted cities in the world, as research objects and analyzes the relationship between fiscal environmental expenditures and the air quality index to explore regulations. Third, using regression discontinuity, this paper introduces environmental policy variables and studies the effects of policy and regional differences on the improvement of air pollution.

Theoretical analysis of the relationship between environmental expenditure and air quality

Environmental protection is an important public good. Because of issues such as the public nature of environmental resources, negative externalities of environmental pollution, and positive externalities of environmental protection, market mechanisms cannot fully play a role in environmental protection, which leads to market failure. As an important necessity, on the one hand, there is a serious shortage of supply of environmental quality; on the other hand, because they are non-exclusive and non-competitive, environmental resources are faced with the intrusion of the "tragedy of commons." The key to solving the above problems is appropriate government intervention in the field of environmental protection through fiscal policy to achieve individual and societal social interest maximization and thus to achieve coordinated development of economic and environmental protection. This means bringing environmental protection into the supply of public goods by

the government to solve the problems instead of requiring the market to solve the problems. In practice, the government often transforms environmental costs into internal costs of enterprises through taxes and then forces enterprises to govern pollution.

Research on environmental issues is mainly based on the theoretical framework of endogenous growth models. Heyes (2000) and Brock and Taylor (2010) introduced fiscal expenditures and environmental quality into the endogenous growth model and indicated the relationship among them. Lawn (2003) and Sim (2006) further expanded the model and concluded that economic development is limited by the environment. The energy consumption of economic development on the environmental Kuznets curve is equal to the amount of energy provided by the environment itself. Furthermore, Dong et al. (2012) and Chen et al. (2013) defined pollution as a function of private capital investment and public expenditure cuts and environmental pollution as a function of the level of output and pollution control. Since output is the main source of pollution, a degree of pollution control by the government can effectively reduce pollution. In the long run, due to the irreversibility of pollution caused by economic development and the spillover characteristics of the environment that cause the failure of the market mechanism, the role of the government becomes important for the efficient operation of the economy. The properties of public environmental goods are closely related to the public interest. Different types of fiscal expenditure policy will affect the "product - money - environment" market.

Based on the above analysis, it is necessary for the government to be involved in environmental protection. In practice, local governments tend to use funds to promote industrial development that significantly contributes to GDP, which will inevitably lead to more environmental pollution. In theory, increasing the energy-saving and environmental expenditure of government can improve regional air quality. However, improvements in air quality refer to many aspects of social production and life. Referring to Li et al. (2013) and Yang et al. (2016), this paper only studies the impact of environmental expenditures on air quality from the aspects of the city's economic development and environment. The paper refers to the GDP, industrial structure, and investment in fixed assets. The rapid growth of China's fixed asset investment has exacerbated industrial wastewater and solid waste emissions and caused a deterioration of the ecological environment (Li and Qi 2011). In fact, on the one hand, government fiscal expenditures can affect the whole economy through industrial investment and can support technological upgrades of enterprises, change the traditional Chinese industrial structure, and then impact the environment. On the other hand, environmental expenditures directly related to fiscal expenditures will also have an impact on the environmental, namely, there is a channel of "financial expenditure (energy saving and

environmental protection) - environmental quality". This paper studies this topic from the perspective of productive factors, so we do not consider consumption factors, such as "population," per capita GDP, population density related to urban economic development, urban area and road passenger traffic related to population, and per capita green area and green coverage related to the urban environment. These relationships of the related factors are shown in Fig. 1.

## Model, variable, and data

Models

The traditional economic growth model mainly uses factors of production, such as physical capital, human capital, and the labor force, to explain economic growth, which ignores the environmental problems caused by economic development. On the one hand, in the endogenous growth model of Barro (1990), government spending is an engine of economic growth, while output is only a function of government expenditure; on the other hand, with the environment constantly worsening, the environmental problems caused by economic development should not be ignored. Therefore, it is necessary to consider both governmental and environmental factors in the endogenous growth model. For governmental factors, Wan (2015) and He and Wang (2015) took government budget and government expenditure, separately into the endogenous growth model to reflect externality of government public investment on economic growth. For environmental factors, Bovenberg and Smulders (1995) introduced the environmental factors into the production function based on the Romer endogenous economic growth model. Besides, Stokey (1998) introduced pollution index into Barro's AK model to study environmental pollution externalities and sustainable economic growth. There are

also some similar researches such as Grimaud and Rouge (2005) and Zou et al. (2014). >Based on the abovementioned researches, government expenditure and environmental quality are introduced into the endogenous growth model in this paper. Thus, in the economic system, human capital investment is divided into human capital development—R&D department of intermediate product development—for final sector production; in the intermediate stage, physical capital needs to be accounted for in the production of intermediate products, which will be sold to the final product sector. Realization of the final product requires labor input; the production process requires an energy input, and the consumption of environmental resources causes pollution. The public goods attribute of the environment needs the government and other departments to invest funds to ensure the normal operation of the entire economic society. In summary, the production function of the final material production sector includes government expenditures and environmental quality can be expressed as follows:

$$Y = F(K, G, H, E, L) \qquad (1)$$

where Y, K, G, H, E, and L represent the final output, physical capital input, government expenditure, human capital, environmental pollution, and labor input, respectively. To simplify the problem, it is assumed that human capital and material capital can be completely replaced (Moon and Sonn 1996). Besides, for labor input, Zheng and Liu (2003) shows labor input of China almost has no impact on constant elasticity of substitution function and Cobb-Douglas function. Xu et al. (2010), and Liu and Yang (2011) believe that labor input is not the core variable when exploring endogenous of environmental expenditures and environmental quality, and consider L is constant at 1. We take the same approach in this paper, and the C-D production function is further written as the

Fig. 1 The impact mechanism of environmental expenditures on air quality
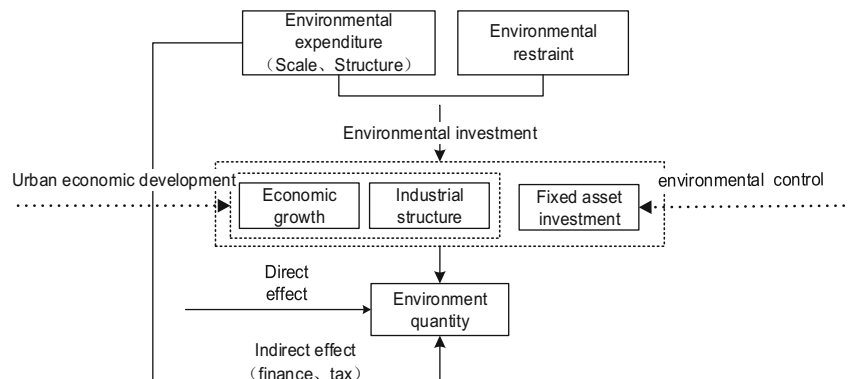
following:

$$Y = BK^{\alpha_1}G^{\alpha_2}E^{\alpha_3}, \alpha_1 + \alpha_2 + \alpha_3 = 1, \ B > 0 \quad (2)$$

To eliminate heteroscedasticity and directly derive elasticity, related variables are expressed as natural logarithms, leading to Expression (3):

$$lnY = \alpha_0 + \alpha_1 lnK + \alpha_2 lnG + \alpha_3 lnE \quad (3)$$

where the constant lnB is denoted by α_0. The equation can be further converted to $lnE = \alpha'_0 + \alpha'_1 lnK + \alpha'_2 lnG + \alpha'_3 lnY$. Since the fixed assets are the real assets of the production capacity of investment, this paper uses the investment in fixed assets FI instead of capital investment K. Government expenditures on energy conservation and environmental expenditures directly affect the quality of the environment, and therefore, environmental expenditures F_{exp} are used as a substitute for government spending G, the air quality index AQI replaces environmental pollution E, and GDP is an alternative variable to output Y. A panel data model for seven heavily polluted cities in China is constructed in model (4).

$$lnAQI_{it} = \beta_i + \beta_1 lnFI_{it} + \beta_2 lnF_{expit} + \beta_3 lnGDP_{it} + \mu_{it} \quad (4)$$

where i represents the cities. T is the year, β_i is the intercept term, and μ_{it} is the random disturbance variable. Furthermore, different industrial structures, as an important link between various economic activities and ecological environment, have different effects on the promotion of economic growth and impact on the quality of the ecological environment (Liu and Huang 2013; Li 2015a, b). Based on the theoretical analysis of this paper, we take the industrial structure as a control variable in Eq. (4). Since the purpose of this study is to explore the influence of environmental expenditure on air quality, variables such as social and economic structures are only used as control variables in the model, as in Expression (5):

$$lnAQI_{it} = \gamma_i + \gamma_1 lnFI_{it} + \gamma_2 lnF_{expit} + \gamma_3 lnGDP_{it} + \gamma_4 lnIS_{it} + \varepsilon_{it} \quad (5)$$

where γ_1 to γ_4 is the elasticity of air quality index to investment in fixed assets, environmental expenditures, GDP, and industrial structure, separately. When the value is great than zero, the air quality is deteriorated with the increase of the independent variable and vice versa.

Furthermore, due to the public goods attribute of environmental resources and the negative externalities of environmental pollution, it is necessary for the government to issue relevant policies and decrees to control growing environmental problems. Based on this, this paper attempts to further analyze the impact of relevant policies on the relationship between the two to judge the effectiveness of environmental policy to a certain extent. Lee (2008) indicates

that the regression discontinuity (RD) method can avoid the endogeneity of parameter estimation when a random experiment is not available, thus truly reflecting the causal relationship among variables. In terms of environmental pollution, Almond et al. (2009) and Xi and Liang (2015a, b) used the regression discontinuity method to test the impact of policy on environmental pollution. Therefore, RD has a great advantage in policy evaluation and causal inference. From a practical point of view, the sixth National Economic and Environmental Conference in 2006 emphasized that the government should shift its way of thinking from only valuing economic growth to attaching equal importance to both economic growth and environmental protection. Thereafter, the central government introduced a series of programmatic documents to develop the low-carbon economy and protect the environment, which also provided the background for environmental policy analysis and research by using RD (Gupta et al. 1995; Xi and Liang 2015a, b). In addition, in the study of the effectiveness of environmental policy, the results are easily affected by endogenous factors, that is, the air quality may not be caused by policies but by other socioeconomic conditions. To overcome the endogenous problems and reduce the interference of omitted variables, taking the research of Lee and Lemieux (2010) as a reference, this paper uses the fuzzy regression discontinuity design method (FRD) to control the variables, such as investment in fixed assets, fiscal expenditure, regional GDP, industrial structure, and other observable variables. A two-stage least squares (TSLS) method is used to estimate the disposition effect. Finally, we obtain Eqs. (6), (7), and (8):

$$lnAQI_{it} = \delta_i + \delta_1 P_{it} + \delta_2 lnFI_{it} + \delta_3 lnGDP_{it} + \delta_4 lnIS_{it} + \varepsilon_{1it} \quad (6)$$

$$lnF_{expit} = \delta'_i + \delta'_1 lnP_{it} + \delta'_1 lnFI_{it} + \delta'_2 lnGDP_{it} + \delta'_3 lnIS_{it} + \varepsilon_{2it} \quad (7)$$

$$lnAQI_{it} = \lambda_i + \lambda_1 lnF_{expit} + \lambda_2 lnFI_{it} + \lambda_3 lnGDP_{it} + \lambda_4 lnIS_{it} + \xi_{it} \quad (8)$$

where P is the policy factor. ε_{1it}, ε_{2it}, and ξ_{it} are random disturbance variables. The first stage regression equation is Eq. (6), and the regression equation of the second stage is Eq. (8). δ_1 and δ'_1 reflect the local average treatment effect of the policy around the time breakpoint, and λ_1 represents the effect of the policy on air quality. To verify the validity of the FDR setting, it is necessary to carry out continuity tests on other control variables that affect air quality and convent the explanatory variables into control variables. In an ideal situation, if the broadband is small enough, other control variables that do not affect air quality directly through environmental expenditures should be

continuous at the point of occurrence of the policy. Then, we obtain Eq. (9).

$$Z_{it} = \theta_i + \theta P_{it} + \upsilon_{it} \tag{9}$$

where Z_{it} is a control variable that affects air quality in different regions of each period, such as economic growth, fixed asset investment, and industrial structure. If the estimated value of θ is insignificant, the assumption of continuity is satisfied. However, Lee and Lemieux (2010) noted that the biggest problem with the above method is that some values of the control variables may randomly have statistically significant differences at the breakpoint. Therefore, it is necessary to combine the tests of several control variables into one test to examine whether θ in the equation corresponding to the control variables is jointly significantly different from 0. A simple way to achieve the above goals is using seemingly unrelated regression (seemingly unrelated regression (SUR)).

Data and preprocessing

Variables and data sources

"China Environmental Status Bulletin 2015" notes that China's environment is unbalanced, the air quality improvement of the Pearl River Delta region is the largest, and the concentration of fine particles in Zhengzhou, Urumqi, and Ji'nan fell in 2014, but rose again after 2015. Meanwhile, there are 70 cities in which the inhalable particulate concentration also rose. In January 14, 2013, an environmental analysis report released by the Asian Development Bank and Tsinghua University noted that of 10 of the world's most polluted cities, 7 are in China, Beijing, Shijiazhuang, Taiyuan, Ji'nan, Chongqing, Lanzhou, and Urumqi. In general, the local governments in heavily polluted areas pay more attention to air quality, and the financial investment in these areas is relatively higher. It is more typical to research the relationship between environmental expenditures and air quality in these

areas. Therefore, this paper tries to analyze the impact of environmental expenditures on the air quality indexes of the seven heavily polluted cities mentioned above from 2007 to 2015. Therefore, in Eq. (7), $i = 1, 2, \ldots, 7$, respectively, represents Taiyuan (TY), Beijing (BJ), Shijiazhuang (SJZ), Ji'nan (JN), Chongqing (CQ), Lanzhou (LZ), and Urumqi (WLMQ).

The variables in this paper are environmental expenditure F_{exp}, air quality index AQI, economic aggregate GDP, industrial structure IS, and fixed assets investment FI. A description of related variables is shown in Table 1.

(1) Environmental expenditure F_{exp} is government expenditure on environmental protection and is part of government investment in environmental protection. Environmental expenditure is used to realize the government's environmental protection function and solve environmental problems. China began to adjust the subject of fiscal expenditure in 2007, and the statistical caliber changed. Moreover, combined with the availability of data, the sample period of this paper is 2007 to 2015. The data are from the statistical yearbooks and websites of finance bureaus of the sample cities.

(2) Air quality index (AQI). AQI is a non-dimensional index that is used to quantitatively describe air quality. A large value signifies more serious environmental pollution and a greater pollution concentration. The Ministry of Environmental Protection of the People's Republic of China began to announce the air quality of key cities in 2000. The original index is the air pollution index API. Then, Ambient Air Quality Standards published by the State Council in the first half of 2012 noted that China will use the air quality index AQI instead of the API to describe the air quality. Compared with the API, the AQI added three pollutants: PM2.5, O_3, and CO. Due to the limitations of the data, the two indexes cannot be converted to each other. Therefore, this paper does not distinguish the API and AQI. We used the air quality index AQI uniformly. In addition, this paper only studies the change trend of air quality pollution and does not focus on investigating the specific numerical situation. Thus,

Table 1 Variable descriptions

Variable	Symbol	Unit	Index description
Environmental expenditure	F_{exp}	Million yuan	Energy-saving and environmental protection expenditure in fiscal expenditure
Air quality index	AQI	mcg/m³	Air quality is measured with API and AQI
Economic aggregate	GDP	Million yuan	Selected gross regional domestic product as an alternative variable to economic aggregate for seven heavily polluted cities in China
Industrial structure	IS	%	The industrial structure is replaced by the proportion of the tertiary industry in GDP
Fixed assets investment	FI	million yuan	Total investment in fixed assets

we take the average yearly air quality (pollution) indices as substitution variables for air quality. It should be noted that because the data for the air quality index in 2013 is unavailable, the average values of the air quality indices of 2014 and 2015 are taken as alternatives to those of the air quality index for 2013. These datasets are from the Ministry of Environmental Protection of China. The unit is mcg/m^3.

(3) Other variables. Except for environmental expenditures, there are many other factors that affect the effectiveness of environmental governance. Based on the research of Yang et al. (2016) and Li and Zheng (2016), we mainly considered the following aspects: first, the urban development (economic) situation. We selected the regional *GDP* (the unit is million yuan) and industrial structure (for the proportion of the tertiary industry in GDP, the unit is %). Second, we considered urban environmental governance. We selected the fixed assets investment index. The unit is millions of yuan.

Changes in the air quality index and environmental expenditures of the sample cities in 2007–2015 are shown in Fig. 2 To facilitate the observation of the relationships of related variables, the relevant data are expressed as natural logarithms.

It can be seen that in 2007–2015, the air quality indices of Beijing, Shijiazhuang, Taiyuan, and Ji'nan fluctuated more widely, while the indices were relatively steady in Lanzhou and Urumqi, which fluctuated by approximately 4.5. In general, air pollution mainly comes from industry, residences, and transportation. As a matter of fact, industry in the seven cities is relatively developed. The provinces (Hebei, Shanxi, Shandong, Gansu, etc.) have abundant energy reserves as well as a large amount of coal mining and consumption. In addition, the industrial system based on fuel

power, machinery, and petrochemicals also exacerbates environmental pollution. Moreover, winter heating of Beijing, Shijiazhuang, Taiyuan, Ji'nan, Lanzhou, and Urumqi is completely dependent on coal, and car ownership in Beijing and Chongqing are ranked first and second, respectively.

As for environmental expenditures, there is no rigid corresponding relationship between environmental expenditure and the air quality index. During 2007–2015, the environmental expenditures of the sample cities had different ranges of growth. The environmental expenditures of Beijing and Chongqing were relatively higher, while they were relatively lower in the other cities. In practice, China's government only recently created energy-saving and environmental protection policies, and some cities do not pay enough attention to these policies. The positive external effects of environmental protection make private capital reluctant to actively participate in the field. However, since there are many factors that can influence air quality and the effect is different in different regions, the relationship between environmental expenditures and the air quality index needs to be further estimated.

Judgment of long-term equilibrium relationship

Before estimating model (5), we first tested the long-term equilibrium relationship between environmental expenditures and air quality to ensure the rationality of the model. The results of the ADF test showed that all of the sequences are I (2), which is the same order single sequence. Then, we used a further test based on the series. Table 2 shows the results of the panel cointegration test.

The PP and ADF tests within and between groups show that at the 1% level, there is a long-term equilibrium relationship between the seven sample cities' air quality index and environmental expenditures. According to the PP and ADF

Fig. 2 Air quality index and environmental expenditure of the sample cities in 2007–2015. The abscissa of 1–7 represent Beijing, Shijiazhuang, Taiyuan, Ji'nan, Chongqing, Lanzhou, and Urumqi, respectively. Figure 4 is the same
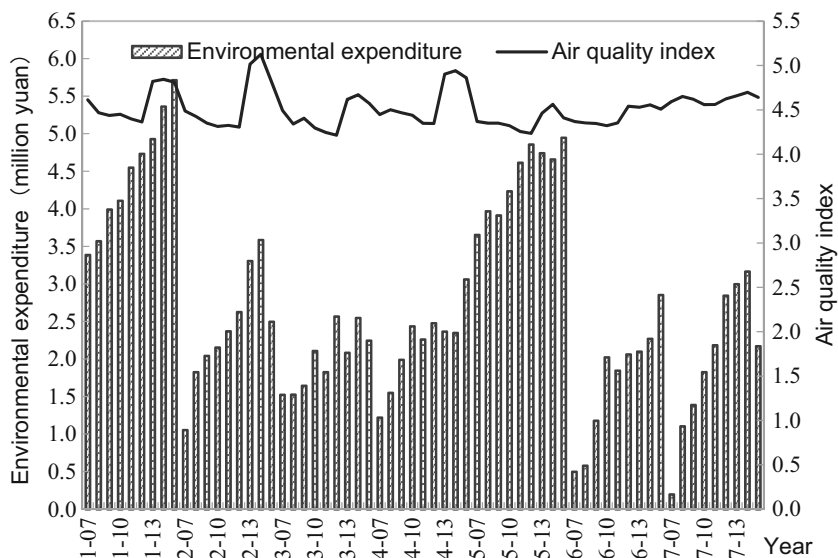
Table 2 Panel cointegration test results

Within-dimension	Environmental expenditure and air quality	Air quality and other control variables	Between-dimension	Environmental expenditure and air quality	Air quality and other control variables
Panel PP	0.2637 (0.0000*)	0.003207 (0.5013)	Group PP	−3.548341 (0.0002*)	−4.657532 (0.0000*)
Panel ADF	−3.819875 (0.0001*)	−0.097166 (0.4613)	Group ADF	−3.285880 (0.0005*)	−2.227755 (0.0129**)

The p value corresponding to each statistic is given in parentheses. *, ** correspond to the 1% and 5% confidence levels to reject the null hypothesis, respectively (The same in Table 3, 5 and 6)

tests between groups, there is also a long-term equilibrium relationship between the regional air quality index and environmental expenditures, fixed assets investments, economic aggregates, and industrial structures. In addition, although the seven cities' environmental expenditures have long been associated with air quality, there are significant regional differences.

Empirical results and analysis

General model estimation

The results of the Hausman test shows (chi-square value, p-values of 5.536965, 0.2365) that a random effects model is reasonable. Based on this, we estimate model (5) with the method of multiple stepwise regression and we find that the model including all the control variables is the best. The results are shown in Table 3.

As seen from Table 3:

(1) Taking the general effects of all of the variables into account, the GDP and industrial structure have significant positive impacts on air quality, and for each 1% increase, the air quality will by improve 0.3813 and 0.5798%, respectively. In fact, the elements of economic

growth can be divided into capital, labor, technology, institutions, and so on. Technology is mainly industry driven because technological innovation cannot be achieved in the short term. In the sample period, the economic development of the seven cities is relatively rapid, and secondary and tertiary industries are the main driving forces promoting economic growth. Li (2015a, b) shows that the environmental pollution situation will be improved as the industrial structure transforms from being dominated by secondary industry to tertiary industry. He further noted that there is an inverted U-shaped curve relationship between environmental pollution emissions and the industrial structure. From the empirical results, the relationship between the industrial structure and environmental pollution of the sample cities is on the right side of the inverted U-shaped curve, and thus, environment pollution improves with economic growth. This result is consistent with the findings of Wang and Huang (2015) and may also be driven by policies.

In terms of capital investment, investment in fixed assets can significantly stimulate industrial development and thus promote economic growth. In recent years, Chinese local governments have gradually become an important investment subject, and the scale and structure of investment in fixed assets directly affect the

Table 3 LS estimation results of the general model

Parameter	Estimated value	Standard deviation	t statistic		p value
γ_i	7.4591	1.2481	5.9762		0.0000*
γ_1	0.2880	0.1093	2.6335		0.0108**
γ_2	0.0507	0.0279	1.8189		0.0741***
γ_3	−0.3813	0.1755	−2.1728		0.0339**
γ_4	−0.5798	0.1545	−3.7534		0.0004*
BJ		−0.0773	CQ		−0.0965
SJZ		0.0604	LZ		−0.0912
TY		−0.0125	WLMQ		0.0922
JN		0.1249			
R^2		0.2301	F statistic		4.3345
adjusted R^2		0.1770	Mean of dependent variable		1.9952
Regressed standard deviation		0.1683	Standard deviation of dependent variable		0.1855
Residual sum of squares		1.6432	Durbin-Watson statistic		0.9521

development of the regional economy. The empirical results show that when investment in fixed assets increases by 1%, the air quality index increases by 0.2880%; investment in fixed assets has an intensified effect on air pollution, which leads to overcapacity in some industries while promoting economic growth in addition to environmental and ecological pressure, causing serious pollution. This result is consistent with the theoretical analysis. However, there is no significant improvement in air quality from environmental expenditure; on the contrary, it exacerbates air pollution to a certain extent. Specifically, for every 1% increase in environmental expenditure, air quality deteriorates by 0.0507%, which is not consistent with the theoretical analysis. However, in fact, environmental expenditures and environmental pollution have a strong spatial spillover (Li, 2016). Local government has an extension mechanism for treating environmental pollution; that is, at lower levels of air pollution, an increase in air pollution has a reduced local environmental expenditure (Xi and Liang 2015a, b). This is the same in the study of Xiong et al. (2016). Second, there are many factors that can lead to the deterioration of air quality. The deterioration of air quality caused by these factors may also offset the improvement from environmental expenditure and result in a positive correlation between environmental expenditure and the air quality index. In addition, regional energy-saving and environmental expenditure policies may lead to different scales of pollution-intensive industries transfer, different extents and types of environmental destruction, and different effects of financial environmental governance. Furthermore, the random effects model only reveals the direct effect of environmental expenditure on air quality; it does not deny the total effect of environmental expenditure on air quality because environmental pollution is the comprehensive result of various factors; therefore, some variables may be omitted. In addition, the irrational investment structure of environmental expenditures and low efficiency of

"input - output" will lead to ineffective environmental governance.

(2) Environmental expenditure has a certain role in improving air quality in Beijing, Taiyuan, Chongqing, and Lanzhou. Table 4 shows environmental expenditure as a share of GDP, and its value is an important indicator of environmental protection issues. As seen from Table 4, the environmental expenditures as a share of the GDP of the four cities are larger than those of other heavily polluted cities. This result highlights that the above four cities attach importance to investing in environmental governance. Furthermore, according to the economic region, Taiyuan belongs to the central region and Chongqing and Lanzhou belong to the western region. In fact, the state has developed many special policies to support the development of the mid-west regions, especially the western region, which will inevitably lead to the emphasis of local governments on the healthy and sustainable development of the local economy. Beijing has one of the most serious cases of haze pollution. Under the international trend of reducing carbon emission, Beijing pays more attention to fiscal policies to air pollution control and guides enterprises regarding technological upgrades and development of the green economy. In other cities, due to their special geographical environments, architectural forms, winter heating (dependent on coal), and lower investment in environmental protection, the environmental governance effect of environmental expenditures may be offset by the effects of other environmental pollution.

Regression discontinuity design

Estimation results and analysis

In general, the air quality index should become smooth over time without a policy intervention. After implementation of a

Table 4 Local environmental protection expenditures as a share of GDP (%)

Time	Beijing	Shijiazhuang	Taiyuan	Ji'nan	Chongqing	Lanzhou	Urumqi
2007	0.30	0.12	0.37	0.13	0.83	0.22	0.10
2008	0.32	0.22	0.31	0.16	0.91	0.21	0.30
2009	0.44	0.26	0.34	0.22	0.77	0.35	0.37
2010	0.43	0.25	0.46	0.29	0.87	0.69	0.46
2011	0.58	0.26	0.30	0.22	1.01	0.47	0.52
2012	0.64	0.31	0.56	0.25	1.13	0.50	0.86
2013	0.70	0.56	0.33	0.20	0.90	0.46	0.91
2014	1.00	0.70	0.50	0.18	0.74	0.48	0.96
2015	1.32	0.22	0.34	0.35	0.90	0.83	0.33

policy, if there is a breakpoint in air quality, it is considered to be the result of an exogenous policy factor. The "Ambient Air Quality Standards" published by the State Council in the first half of 2012 showed that the air quality index (AQI) can be substituted for the original air pollution index (API) to describe the air quality. Compared with the API, the AQI added three other pollutants: PM2.5, O_3, and CO. Therefore, we only take the environmental protection policy during 2007–2011

into account in this paper. In Fig. 3, the vertical axis is the air quality compliance rate, measured by the proportion of days that excellent air quality reached the standard. As the value increases, the effect of the policy becomes more positive. The vertical line is the line dividing of the policy effects.

The result shows that the air quality standard-reaching rate appeared to be discontinuous in 2009 in the seven cities. However, the air quality in Jinan, Chongqing, and Urumqi

Fig. 3 Changes in air quality in seven cities before and after implementation of the fuel tax policy

(1) Taiyuan

(2) Beijing

(3) Shijiazhuang

(4) Ji'nan

(5) Chongqing

(6) Lanzhou

(7) Urumqi
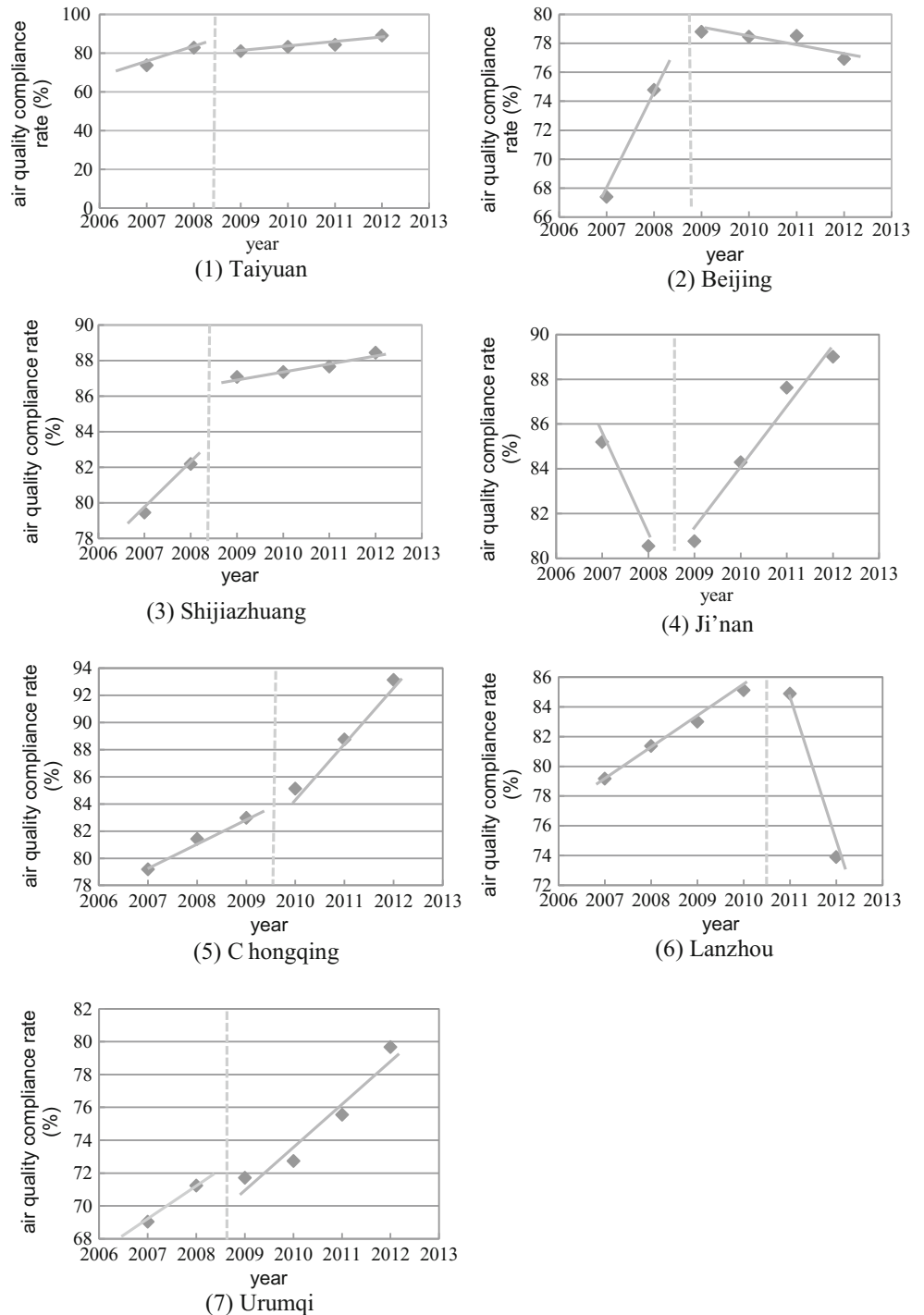
deteriorated after the discontinuity. This probably occurred because the environmental expenditure scale, economic level, and industrial structure are different in different regions as well as because there is a time lag for implementation of the policy, and the probability that the air quality will be affected by the policy will increase over time, while the policy effect will inevitably be overestimated or underestimated. In fact, in the sample period, the policies that directly countered air pollution were "Law of the People's Republic of China on Conserving Energy" (2007), "Guiding Opinions on Further Strengthening the work of energy saving and emission reduction for small and medium sized enterprises" (2010), "Emission standard of Air Pollutants for Thermal Power Plants" (2011), and the "Fuel tax policy," which were implemented on January 1, 2009. Combined with the analysis of the results of Fig. 3, this paper chose the fuel tax policy as the object of study. We used the dummy variable P ($P = 1$, if the time is 2009 and after; otherwise, $P = 0$) as the instrumental variable affected by policy (year). In addition, we took the related variables affected by the policy after 2009 as the treatment group and variables before 2009 as the control group. The estimation results of the regression discontinuity design are shown in Table 5.

We can see:

(1) According to the estimation results of Eq. (6) and (7), the effect of the fuel tax policy on air quality is insignificant in general, and there is a small positive effect. For every 1% increase in fuel duty, the air quality deteriorates by 0.0021%, and there is a persistent effect. However, compared with the estimated results of model (5), the results show that the effect of the fuel tax policy on air quality improvement has more potential than that of environmental expenditure, which also reflects the effectiveness of the policy to some extent. For this reason, the implementation of the fuel tax policy has a time lag effect and air pollution is the result of the comprehensive effect of multiple factors, such as coal-based energy and secondary industry-led industrial structure; on the other hand,

the effect of local energy-saving and environmental protection expenditure on air pollution is insignificant, probably because local governments focus on a certain type of pollution indicator of energy conservation and environmental protection and ignore the other governance indicators. For example, the focus of local governments on water pollution and CO_2 emission control may provide more opportunities for SO_2 emissions from industrial enterprises (Xiong et al. 2016). In addition, implementation of the fuel tax will directly affect the use of gasoline and diesel and will affect automobile exhaust emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxide (NOX), lead (Pb), and other emissions. Therefore, the fuel tax has a greater effect on improving air quality relative to environmental expenditure.

(2) The estimation results of Eq. (8) show that the deterioration effect of environmental expenditure on air quality is reduced from 0.0507 to 0.0048% when the fuel tax policy is taken into consideration. In addition, investment in fixed assets will exacerbate environmental pollution, while economic growth and the industrial structure can alleviate pollution. These results are consistent with the results of the random effect model. Moreover, when the effect of the policy is considered, the influence of other control variables on air quality does not changed significantly, which reflects the robustness of the regression discontinuity design model (Xi and Sun 2017).

Furthermore, to analyze the differences in the role of policies in different cities, a regression analysis based on time series is performed for the seven cities. The results are shown in Table 6. It can be seen that implementation of the fuel tax policy has not improved the air quality of Beijing, Taiyuan, Jinan, Lanzhou, and Urumqi. However, the effect is relatively more obvious in Shijiazhuang and Chongqing. The air quality indices of the two cities decreased by 1.56887 and 0.0921%, respectively. This type of difference is probably related to the game between the interest groups and positive cooperation

Table 5 Estimated results of the regression discontinuity

Parameter	Estimated value	Standard deviation	t statistic	p value
Logarithmic air quality simplification equation				
δ_1	0.0021	0.0638	0.03	0.974
Logarithmic environmental expenditure simplification equation				
δ_1'	0.4384	0.1880	2.33	0.023**
Logarithmic air quality structural equation				
λ_1	0.0048	0.0948	0.05	0.959
λ_2	0.2485	0.1234	2.01	0.044**
λ_3	−0.3011	0.1191	−2.53	0.011**
λ_4	−0.5254	0.1185	−4.43	0.000*

Table 6 Estimation results of the regional regression discontinuity design

Area	Estimated value of δ_1	Estimated value of λ_1
BJ	0.0130 (0.945)	−2.4988 (0.714)
SJZ	−1.5687 (0.097)***	0.5913 (0.0000)*
TY	0.1540 (0.680)	−0.0944 (0.754)
JN	0.4384 (0.023)**	0.0048 (0.959)
CQ	−0.0921 (0.481)	0.0846 (0.915)
LZ	0.4384 (0.023)**	0.0048 (0.959)
WLMQ	0.1798 (0.687)	−0.2298 (0.680)

Table 8 Results of the validity test

Parameter	Estimated value	p value	SE	Z
LnFI	0.1731	0.711	0.4680	0.37
LnGDP	0.1717	0.709	0.4595	0.37
LnIS	−0.0688	0.3835	0.0119	−0.87

between the central and local governments. In addition, the positive effects of the environmental expenditures on air quality in Beijing, Taiyuan, and Urumqi were 2.4988, 0.0944, and 0.2298%, respectively. When the fuel tax policy is taken into account, the improvement of Beijing's environmental expenditure on air quality significantly increased from 0.0773 to 2.4988%, which highlights the role of coordination between environmental expenditure and fuel tax policy.

Robustness test

To verify the rationality of the estimation results, this paper tests the robustness of the relevant variables further. Taking the research of Lei et al. (2015) as a reference, according to the design principle of the regression discontinuity design, the unobservable factors of the treatment group and control group do not vary with time and are the same or similar. Whether the control variables are considered or not, they do not affect the final results. The sensitivity of models (6) and (8) were analyzed by the method of one addition and stepwise addition, and the results are shown in Table 7.

We can see that the effects of environmental expenditure on air quality do not change and are all positive when the control variables are not considered as well as when the investment in

fixed assets, economic growth, and industrial structure variables are successively added to the model. In addition, in terms of the impact on air quality, investment in fixed assets, economic growth, and industrial structure enhanced the improvement effect of the fuel tax on air quality. When the control variables are not considered, there are no large differences in the results. This result reflects the effectiveness of instrumental variable selection.

Validity test

To test the continuous changes of other effects over time, except for the discontinuity on the fuel tax policy, model (9) was estimated, and the results are shown in Table 8.

In general, before the discontinuity in 2009, the control variables should not be restricted by the fuel tax policy. According to the regression results, the coefficients are all insignificant at the 5% confidence level, which indicates that the control variables in the model are not truncated in the sample period and that the related factors have no significant differences at the time of policy implementation. In Fig. 4, we took the investment in the fixed asset as an example and can see that there was no obvious jump on both sides of the discontinuity in 2009 in the sample cities. Therefore, it is representative of the economic aggregate and industrial structure (figures are omitted) and verifies the effectiveness of the empirical results to a certain extent.
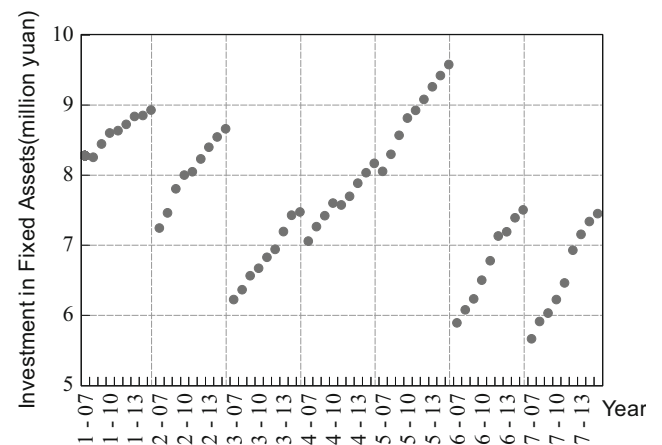
Table 7 Results of the robustness test

Parameter	Estimated value	t (z) statistic	p value
Without control variables			
δ_1	1.1911	3.10	0.003*
λ_1	0.0546	1.38	0.167
With investment in fixed asset			
δ_1	0.2950	1.65	0.105
λ_1	0.1561	0.90	0.367
With investment in fixed asset, economic growth, industrial structure			
δ_1	0.4384	2.33	0.023**
λ_1	0.0048	0.05	0.959

δ_1 and λ_1 correspond to the value of t and the Z value, respectively

Fig. 4 Validity test of the investment in fixed assets in the seven cities

Conclusions

This paper tests the relationship between the environmental expenditures and air quality of seven typical heavily polluted cities in China and further analyzes the effect of the fuel tax policy on improving air quality by using a regression discontinuity design. We find that first, there is a long-term equilibrium relationship among environmental expenditure, air quality, and investment in fixed assets, economic aggregate, and the industrial structure, and the impact of relevant variables on air quality is significantly different in different regions. In general, the effect of environmental pollution expenditure on the improvement in air pollution is insignificant and even has a deterioration effect of 0.0507%. However, for the sample cities, environmental expenditure produces improvement effects on air quality of 0.0733, 0.0125, 0.0965, and 0.0912% in Beijing, Taiyuan, Chongqing, and Lanzhou, respectively, while the effects in Shijiazhuang, Ji'nan, and Urumqi are relatively insignificant. These results can probably be ascribed to the proportion of regional environmental protection investment as a percentage of GDP. In fact, the proportion of regional environmental protection investment as a percentage of GDP, to some extent, can reflect the importance of local government give to environmental protection. In Beijing, Taiyuan, Chongqing, and Lanzhou, the proportion is relatively high and the government's investment in environmental protection can effectively transformed into the improvement of air quality. The situation in Shijiazhuang, Ji'nan, and Urumqi is the opposite. Second, the investment in fixed assets, economic growth, and industrial structure, among other factors, can significantly affect air quality, and economic growth and industrial optimization can effectively promote an improvement in air quality. This result indicates that the relationship of economic growth, industrial structure, and environmental pollution is on the right side of the traditional inverted U-shaped curve for the seven sample cities. In addition, the investment in fixed assets aggravates environmental pollution, which is consistent with the theoretical analysis. Third, implementation of a fuel tax policy in 2009 eased the deterioration of environmental expenditure on air quality, and the effect decreased from 0.0507 to 0.0048%. This result highlights the effectiveness of the fuel tax in improving air quality. In addition, the effects of the fuel tax policy in Shijiazhuang and Chongqing are relatively more significant than in the other cities, which is probably related to the local government executive ability.

Based on the results of empirical research, the policy focus in practice should be first, empirical analysis shows that fiscal policy does not play a significant role in improving air quality as a whole, but coordination among policies can improve air quality. Therefore, the local governments especially the governments whose environmental expenditure has insignificant improvement effects on air quality such as Shijiazhuang, Ji'nan, and Urumqi should not only increase their investment in environmental protection via fiscal expenditures, but also cooperatively implement relevant policies as well. In addition, the difference in regional environmental expenditures seriously affects the equality of basic public services in the regional environment and restricts the improvement of the overall environmental management level; thus, inter-regional collaborative governance should be promoted. Second, the structure of environmental expenditures should be optimized to increase emission reductions of major pollutants, improve the efficiency of environmental expenditure, and encourage government and enterprises to increase the development of the environmental protection industry by encouraging enterprises to increase production of environmental protection products and pollution control. Third, the effect of the fuel tax policy on air quality improvements is not obvious, and urban pollution continuously increases. Therefore, the fuel tax policy should be further improved. For example, different rates for different fuels and different incentives for different groups should be considered in practice. In addition, in addition to the fuel rate policy, other relevant tax policies should be cooperatively improved as well.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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