Vertical Management Reform of Environmental Protection System and Air Quality Improvement: Empirical Test Based on RDD

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Abstract. As a major institutional innovation in the field of environmental protection system, the supervision and law enforcement of environmental protection system in China has been transformed from the jurisdictional management system to a vertical management system, and its effect on improving air quality is a hot issue to be tested urgently. This paper uses regression discontinuity design model (RDD) to test the daily air quality of 321 prefecture-level cities from September 2016 to December 2019. The results show that the vertical management reform of environmental protection system can significantly improve the air quality, and has a significant long-term inhibitory and sustainable effect on air pollution. Furthermore, a series of robustness tests also further prove the reliability of the results. As a conclusion, this paper provides a basis for decision-making in deepening the vertical management reform of environmental protection system.

1 Introduction

Over the past 40 years of reform and opening up, China's economy has achieved rapid growth, however, it has also generated serious environmental pollution problems, among which air pollution is more prominent. According to the data statistics in the 2018 China Ecological Environment Status Bulletin, among 338 cities above prefecture level nationwide, 217 cities exceeded the air pollution standard, accounting for 64.2%, and the air pollution problem is still very serious. As known, the air pollution problem seriously affects the health of the population. Chen et al. (2013) find that air pollution caused by coal burning for winter heating leads to a 5.5-year shortening of the average life expectancy of the population in northern China.

Since the natural environment is a public resource that is non-competitive and non-exclusive, the market will fail in regulating pollution control inputs, and the government should take the lead in environmental management. In China, there are two modes of administrative management: jurisdictional management and vertical management (Yin,

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2011). Jurisdictional management system implements the operation mode of "combination of stripe and block, block-based, hierarchical management", in which the "stripe" refers to the central ministry and the vertical management system under the leadership of the central ministry, while the "block" refers to local governments at all levels and functional departments under the leadership of local governments. Under this system above, local environmental protection departments are under the "dual leadership" of higher authorities and local governments. If the goals of the central government and local governments are not in line, local governments influence local environmental protection departments through "people, finance, and materials", resulting in a tendency for these departments to carry out the orders of the local government.

The environmental protection departments have been managed on a jurisdictional mechanism since 1973. Local governments are responsible for economic development, culture and education, health care and social welfare, etc. In order to solve problems of the current block-based local environmental protection management system, make up for the shortcomings of the ecological environment and crack the bottleneck of development brought about by environmental pollution, on September 22, 2016, the General Office of the CPC Central Committee and the General Office of the State Council issued the "Guidance on the pilot reform of the vertical management system of monitoring and enforcement of environmental protection agencies below the provincial level" (referred to as "Guidance"). The "Guidance" requires that the environmental supervision function of the environmental protection departments at city and county levels be returned to the provincial environmental protection department, which can exercise a unified environmental monitoring functions through the form of dispatch to cities or cross-city and cross-county regions. After the Guidance was issued, 12 provinces (cities), including Hebei, Shanghai, Jiangsu, Fujian, Shandong, Henan, Hubei, Guangdong, Chongqing, Guizhou, Shaanxi, and Qinghai, applied for pilot reform and carried out preliminary preparatory work such as drafting reform implementation plans.

In this paper we use the vertical management reform in the environmental protection system as a "quasi-natural experiment”. By collecting air quality data, meteorological data and the date of completion of vertical management reform for 321 prefectures across China, we make use of regression discontinuity design model to test the effect of the vertical management reform in the environmental protection system on air quality improvement and evaluate the effect of the reform in China. Compared with the existing studies, the possible marginal contributions of this paper are: first, it provides reliable and realistic evidence for assessing the environmental governance effects of the vertical management reform in the environmental protection system currently being promoted in China. Based on the fact that the vertical management reform of China's environmental protection system has been initially completed, but little research has been done to evaluate its policy effects, we seek to explore research on this topic; second, it provides a reference for Chinese administrations to choose between jurisdictional and vertical management optimal operating systems. Because both jurisdictional and vertical management systems have their own advantages and disadvantages, the administration should conduct a policy effect evaluation after implementing the reform, and then determine the direction of the reform based on the evaluation results. This paper enriches the research related to the two management systems.

2 Review of the literature

There are two types of literature related to the research topic of this paper. The first type of literature is about the comparative analysis of theories of jurisdictional and vertical management systems, and the second type is a series of literature on governmental air pollution control.

In the first type of literature, most scholars have comparatively analyzed the choice between jurisdictional and vertical management under different task combinations by constructing various models (Yin, 2011; Wang and Pan, 2010; Yin et al., 2011). Other scholars have comparatively analyzed the regulatory performance of the two systems from the perspective of the regulator's supervision (Yin and Gui, 2015). Regarding the comparative analysis of the two systems in the environmental protection departments, some scholars have studied that the balance between the decentralization of local governments and environmental protection departments should be dynamically adjusted in a reasonable way to achieve a cooperative and co-governance pattern with symmetrical rights and responsibilities between them (Zhang and Zhang, 2018). Most of the extant literature is based on relevant theories for derivation, lack of empirical testing research. In addition, the comparative analysis is conducted on market regulators that have been implementing vertical management policies for many years, and there is a lack of empirical testing of the effects for vertical management reforms on environmental monitoring and enforcement.

The second type of literature is the research related to government air pollution control. there is literature examining whether the implementation of specific government policies or the application of some measures has reduced air pollution. For instance, the implementation of Beijing's road restriction policy, the "Air Ten", the "Two Sessions", the interview and the central environmental supervision policy have effectively reduced the air pollution level. Zhao et al. (2019) employ difference-in-difference method to test the environmental governance effect of vertical management reform of environmental protection system in Shaanxi Province, and the results show that the implementation of vertical management by environmental protection departments can significantly improve environmental governance. However, this study is only limited to a provincial context and does not examine the policy effects in a larger space with only PM2.5 single pollutant data used. This paper examines the effect of vertical management reform on air quality across the country using data of six pollutants.

3 Study design and data

3.1 Model design

The regression discontinuity design method (RDD) is used to evaluate the effect of vertical management reform on air pollution control in this paper. The basic idea of RDD is to find a suitable exogenous distributive variable in an exogenously changing environment that causes sudden changes in the dependent variable, but does not directly affect the relationship between other variables and the dependent variable. From this, the extent to which changes in the dependent variable are caused by exogenous distributional variables can be estimated, and then the causal relationship between the two is verified. The RDD which is a proposed randomized method second only to randomized experiments has been used extensively in the literature to study air pollution, for example, using time as a breakpoint to examine whether air quality changes before and after an event (Viard and Fu, 2015; Davis, 2008). In the assessment of the implementation for vertical management reform policies in environmental protection systems, if a "jump" in the air quality index is observed before and after the implementation of a vertical management reform city policy, while other factors affecting the air quality index have been changing continuously before and after the implementation of this policy, then it is reasonable to believe that the sudden change in air quality is caused by the implementation of the vertical management reform policy, which means that the implementation of the vertical management reform policy has an air pollution control effect.

There are two methods of RDD estimation, parametric and nonparametric. The parametric method is adopted in this paper. According to the local experimental effects of RDD (Imbens and Lemieus, 2008), the model is set as follows. Spring Festival travel rush last from January 10 to February 18, 2020.

$$AQI_{cd} = \alpha_0 + \alpha_1 CHUIGAI_{cd} + \alpha_2(t - c_c) + \alpha_3 CHUAIGAI_{cd}(t - c_c) + \lambda X_{cd} + \delta_c + \varphi_d + \varepsilon_{cd} \quad ((c_c - h) < t < (c_c + h)) \tag{1}$$

Where the subscript c represents the city where it is located, the subscript d indicates the corresponding date (year, month, and day), the explanatory variable AQI_{cd} represents the air quality index, and $CHUIGAI_{cd}$ represents the dummy variable for completing the vertical management reform work, $CHUIGAI_{cd}$ =1, otherwise $CHUIGAI_{cd}$ =0; t represents the date and c_c is the completion date of vertical management in the prefecture-level city, X_{cd} is a set of weather control variables, mainly containing variables, which are used to control the impact of weather change factors on air quality; δ_c is a fixed effect of city; φ_d is a fixed effect of time and the year, month, week, legal holidays and seasons are controlled separately in this paper to control the impact of date factors and people's work schedules on air quality; ε_{cd} is the random error term; h represents the bandwidth, indicating the time region of the sample data. In equation (1), α_3 is the impact coefficient of vertical management reform, which is the core coefficient of this paper's study, and exactly captures the difference of air quality before and after the implementation of vertical management reform. Based on equation (1), the model setting is refined to the daily degree of prefecture-level cities.

For the RDD model, there is a correlation between the choice of h (bandwidth) and the results. The smaller the h is, the smaller the bias is. However, the smaller h is with the larger the variance due to the small number of samples. In this paper, the optimal bandwidth is selected by using a method that minimizes the mean square error (MSE) at the breakpoint of the two regression functions (Imbens and Kalyanaraman, 2012).

3.2 Data sources

The Air Quality Index (AQI) used in this paper is a quantitative description of the air quality level, which is a comprehensive reflection of the daily air quality for a city, widely concerned by the public and valued by the national environmental protection departments. AQI is the maximum value of the sub AQI values calculated separately from each individual pollutant concentration index. The AQI value range is located between 0-500 and is an inverse indicator, the larger the number, the worse the air quality. According to the size of AQI, the city air quality is divided into six grades, which are excellent (AQI between 0-50), good (AQI between 51-100), light pollution (AQI between 101-150), moderate pollution (AQI between 151-200), heavy pollution (AQI between 201-300 and severe pollution (AQI between 301-500).

Before 2014, China only published the Air Pollution Index (API) which contains only three pollutants, SO2, NO2 and PM10, while AQI is newly added three pollutants, PM2.5, CO and O3. Besides, the frequency of reporting for AQI increase from daily to hourly, and PM2.5 is the main cause of hazy weather, therefore AQI is a better indicator of air quality. In general, the daily AQI and individual pollutant indices are more concerned and have a higher utilization rate. Currently, there are several channels to obtain AQI on the Internet. In this paper, we adopt the historical daily data provided by the "China Air Quality Online

Monitoring and Analysis Platform", which contains daily AQI and daily average values of six individual pollutant concentrations. In addition, the "China Air Quality Online Monitoring and Analysis Platform" publishes monthly AQI data, and this paper uses monthly AQI and weekly AQI calculated from daily AQI data as the proxy variables for robustness testing.

The completion time of vertical management reform in each prefecture-level city is defined by the time when the first county-level ecological and environmental bureau was listed and established in that prefecture-level city. The time data including the completion time of 321 prefecture-level cities is manually collected by searching the press release from the Ministry of Ecology and Environment's website, China Environment News and search engine searches. Python language and Stata 16.0 software are used for data processing.

One possible reason is that more rural labor force flows into cities to seek job opportunities after the Spring Festival, which meets the demand for labor force in cities. However, in 2020, due to the outbreak of the pandemic, the population moving out before the Spring Festival could not return normally, resulting in employment gaps in all cities. The employment gaps in almost all cities are positive, with a maximum of 196.91 and an average of 12.85.

3.3 Statistical analysis

From the descriptive statistics of the main variables for the full sample, we can see that the average value of AQI is 77.19, which is in the second rank of "good" among the six ranks, indicating that the average air quality is good during the sample period, but from the maximum and minimum values of AQI, we can see that there are great differences among cities and time. By sorting the AQI values, we find that 28.28% of the days with excellent air quality, 51.47% of the days with good air quality, 14.27% of the days with light pollution, 3.52% of the days with moderate pollution, and 1.97% of the days with heavy air pollution and 0.14% of the days with severe pollution. From the statistics, the air quality in China's prefecture-level cities is mainly good, followed by excellent, and the total number of days with light, moderate, heavy and severe pollution only accounts for about 20%, indicating that environmental management has achieved significant results.

4 Empirical analysis

Next, we examine the air quality improvement effect of the vertical management reform for the environmental protection system in terms of benchmark analysis, robustness test.

4.1 Benchmark regression results

In the Benchmark regression, as mentioned earlier, the optimal bandwidth which is calculated using the MSE method in Stata software in this paper, is approximately 82 days. Since adding control variables to the regression can reduce the residuals of the model while the estimation error of the coefficients of the control variables affects the estimation efficiency (Xu and Zhang, 2018), this paper includes both cases with and without control variables in the analysis of the regression results. Firstly, RDD is performed using different multiples of the optimal bandwidth without adding control variables.

In this paper we focus on the coefficient of the interaction term CHUIGAI*(t-cc) -which is the impact coefficient of the vertical management reform and captures the difference in air quality changes before and after the implementation of the vertical management reform. As can be seen from the regression results, are 0.1940 and 0.0411 at 0.5times and 1times optimal bandwidth, respectively. Although it has a positive and significant impact on AQI, the coefficient value has a decreasing trend. However, the coefficients of vertical reform policy are -0.0809, -0.0869, and -0.0831 at 1.5times, 2times, and 2.5times optimal bandwidth, respectively, and all of them are significant at the1% level, indicating that the vertical reform policy has a significant negative effect on AQI, confirming that the vertical management reform policy has a significant enhancement effect on air quality. It is also clear from the regression results that the vertical management reform policy cannot produce immediate air quality improvement effects and requires a buffer time for policy implementation. This is also consistent with the findings of existing literature, for example, Wang, (2019) finds that environmental interviews have a treatment effect on AQI, but the coefficient only passes the significance test at 2 times optimal bandwidth of about 8.3 months.

There are many factors affecting air quality. We proceed to regression analysis after adding control variables such as meteorological factors and time factors, and the regression results are shown in Table 1.

From the regression results, it can be seen that are significant at the1% and the10% level at 0.5 times and 1 times optimal bandwidth, respectively, with a decreasing trend in the significance level, and the values of are 0.2020 and 0.0290, respectively, again with a decreasing trend. However, the values of are negative at 1.5 times, 2 times and 2.5 times optimal bandwidth, and all of them are significant at the1% level, which confirms the robustness of the results and that the effect of the vertical management reform policy for the environmental protection system on air quality improvement is highly significant. The above regression results indicate that the reform can effectively enhance air quality and improve air pollution, but there is a significant lag effect. In other words, the vertical management reform policy has a long-term and sustainable effect on air pollution management and can effectively play the inspector function, thus to curb air pollution and improve air quality.

Along with the RDD, scatter plots and fitted curves at1times and 1.5times optimal bandwidth near the breakpoint are plotted in this paper, respectively, as shown in Figure 3. The nonparametric fit plots show that the binomial function well fits the AQI data at 1times and 1.5 times optimal bandwidth before and after the completion of the vertical management reform policy, and there is a clear breakpoint near the completion of the reform. As can be seen from figure 1, the comparison of the two subplots, the AQI on the left side near the breakpoint shows a downward trend representing air quality improvement, and the AQI on the right side rises and then falls representing air quality declining and then improving. The possible reason is that the" adjustment costs" and "frictional costs" caused by significant change in the affiliation of environmental monitoring and enforcement departments after the reform and the possible mismatch of resources exceed the effect of the reform policy, resulting in a short-term decline in air quality, but after a period of adjustment and rationalization, the effect of the vertical reform policy is highlighted, and air quality is significantly improved.

Table 1. Regression results at different multiples optimal bandwidth (82 days, with control variables)

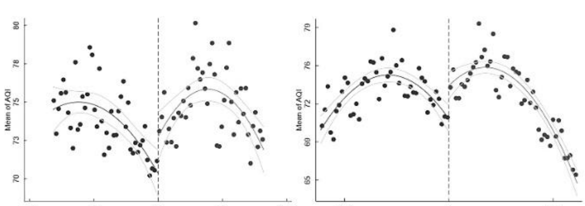
variable	AQI (1)	AQI (2)	AQI (3)	AQI (4)	AQI (5)
	0.5times	optimal	1.5times	2times	2.5times
CHUIGAI	1.2580	2.6150***	2.7800***	1.9410***	2.5510***
	(1.33)	(3.76)	(4.79)	(3.77)	(5.51)
$t\text{-}c_c$	-0.0710**	-0.0274**	0.0195***	0.0327***	0.0280***
	(-2.48)	(-2.44)	(3.08)	(7.66)	(9.18)
$CHUIGAI*(t\text{-}c_c)$	0.2020***	0.0290*	-0.0735***	-	-0.0630***
	(4.94)	(1.92)	(-8.86)	(-12.80)	(-15.99)
Controls	Yes	Yes	Yes	Yes	Yes
cons	-7122.4***	-3805.7***	-2161.7***	1736.2**	4207.1***
	(-4.06)	(-3.62)	(-2.74)	(2.33)	(6.23)
Sample	26 600	52 847	78 973	104 355	130 935

4.2 Robustness tests

4.2.1 Bandwidth sensitivity

The robustness of the RDD results is greatly affected by the bandwidth. To verify the robustness of the benchmark regression results, we use the Local quadratic regression method in nonparametric RDD to calculate the optimal bandwidth to obtain 97 days, and perform regression analysis at 0.5times, 1times, 1.5times, 2times, and 2.5times optimal bandwidth in turn.

The results show that the vertical management reform policy of the environmental protection system significantly improves air pollution and enhances air quality at more than 1times optimal bandwidth, supporting the conclusions of this paper. Obviously, the conclusion that the vertical management reform policy of the environmental protection system has an enhancing effect on air quality, as drawn in the benchmark analysis, is robust.



A optimal bandwidth B 1.5 times optimal bandwidth

Fig. 1. AQI fitted curves before and after the completion of the vertical management reform.

4.2.2 Single pollutant

AQI is the largest value among the indexed concentration data of each of the six pollutants. To verify the robustness of the benchmark regression results, the daily averages of the historical daily data for the six individual pollutants provided by the "China Air Quality

Online Monitoring and Analysis Platform" are used as the dependent variables for the RDD analysis.

The results indicate that the vertical management reform policy of the environmental protection system has a significant inhibitory effect on PM2.5, PM10, SO2, NO2 and CO, but has no obvious governance effect on O3, which may be related to the formations and sources of O3. O3 that is a secondary pollutant, mainly the photochemical reaction of volatile organic compounds and nitrogen oxides in the air under the action of sunlight, requires more complex treatment methods. Therefore, that the implementation of the vertical management reform policy has no obvious impact on it in the short term, is also reasonable. The relevant data on the "2018 China Ecological and Environmental Bulletin" shows that the O3 concentration and the proportion of days exceeding the standard for it are on the rise while the concentration of the other five pollutants and the proportion of days exceeding the standard for these pollutants are on the decline, consistent with the conclusion of this paper. It can be seen from the regression results that the significance and sign of the regression coefficients are consistent with the benchmark regression conclusions, confirming the robustness of the conclusions.

5 Conclusions and suggestions

In this paper, by adopting a RDD, we empirically test the air quality enhancement effect of the vertical management reform in environmental protection system, and analyze the heterogeneity of the vertical reform policy effect. We use daily air quality data for 321 prefecture-level cities from September 2016 to December 2019. The results show that the vertical management reform in the environmental protection system significantly improves air quality, and the improvement effect is long-lasting and persistent, requiring a certain amount of time to highlight the policy reform effect.

Based on the results of the empirical study in this paper, the following policy recommendations are made.

Firstly, the empirical results show that the reform work takes a certain amount of time to highlight the effect of improving air quality. Therefore, the Ministry of Ecology and Environment should continue to adhere to and deepen the environmental protection system supervision to ensure the independence of environmental supervision and law enforcement, and avoid various interventions by local governments.

Secondly, vertical management reform relies on the operational efficiency of local governments, and the central government should focus on local governments that have not completed their reform work on schedule and find ways to improve their operational efficiency and management levels. The Ministry of Ecology and Environment continues to implement the main responsibility of local governments for environmental protection by incorporating various indicators of environmental protection into the assessment system and promotion system.

Authors' contributions

Aili Du: Conceptualization, Methodology. Lei Wang: Data Curation, Formal analysis, Writing- Original draft preparation. Aili Du: Project administration, Supervision, Validation. Aili Du: Writing-Reviewing and Editing.

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