Does the pollutant charging system effectively reduce PM$_{2.5}$ concentration? Evidence from 255 cities in China

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Abstract: Based on the panel data of 255 Chinese cities from 2007 to 2015, this paper empirically analyzes the impact of the Pollutant Charge System (PCS) on PM$_{2.5}$ concentration. At the same time, a heterogeneous analysis of the level of economic development, pollution level, and local leadership characteristics was carried out. The results found that: First, when the levied price of sulfur dioxide emissions increases by 1 RMB/kg, the PM$_{2.5}$ concentration drops by 1.307 mg/m$^3$. Secondly, the lower the economic level, the better the effect of PCS on haze pollution control. Third, the lower the PM$_{2.5}$ concentration, the better the effect of PCS on haze pollution control. Fourth, in cities where the mayor has working experience in state-owned enterprises, PCS has a better control effect on haze pollution. Finally, three suggestions were made.

JEL Classification: C33; Q53; Q58

1. Introduction

China's haze pollution is becoming more and more serious and has attracted the attention of the public all over the world (1). According to the "Report on the State of the Environment in China (2018)", among China's 338 prefecture-level and above cities, 217 of them exceed environmental air quality standards, accounting for 64.2% (2). Haze pollution has caused far-reaching adverse effects on public health (3-6) and the economy (7, 8). The Chinese government has issued a series of environmental regulations and policies to reduce haze pollution (9). Hashmi et al. (2019) and Yu et al. (2019) also pointed out that the control of haze pollution largely depends on the intensity, supervision and implementation of environmental regulations (10, 11).

China's environmental regulations can be divided into three types: command-and-control regulation (CCR), market-based regulation (MBR) and voluntary regulation (VR) (12). Traditionally, the government has relied heavily on CCR. Although the regulations are effective, they are usually inefficient (13). In recent years, the Chinese government has begun to experiment with various MBRs, such as subsidy policies, tradable pollution permits, taxation, and Pollutant charging system (PCS) (14, 15). It is believed that these tools provide companies with a more flexible mechanism to protect the environment, while adjusting production processes, reallocating resources, and innovating (13). The status of MBR in China is constantly improving.

China's MBR mainly includes PCS and emission trading policies. China's PCS is mature, but the
emission trading policy is still in the pilot phase (16, 17). PCS is mainly used by the government to set pollutant emission prices, which mainly include pollutants such as sulfur dioxide. Subsequently, the government charged companies based on their actual pollutant emissions. Since it was enacted in 2003 until it was replaced by an environmental tax in 2018, PCS has been the most important MBR in China (15).

Haze pollution is mainly composed of sulfur dioxide, nitrogen oxides and inhalable particulate matter, and the culprit is PM$_{2.5}$ particles (15). Studying the impact of PCS on PM$_{2.5}$ concentration will help further improve China’s MBR, such as environmental taxes. However, most of the current research on PCS focuses on corporate productivity, corporate sustainable development and green productivity (12, 18). There are relatively few studies on the effect of China's MBR on haze pollution, and there are limitations, especially PCS. Most of the literature on PCS is based on sample data at the provincial level, such as Guo et al. (2017), Xie et al. (2017) and Zhang et al. (2020a) (15, 16, 19). Limited to the provincial panel data, the research sample size is small, and the heterogeneity of the city level cannot be recognized. As far as we know, there is no literature using city-level data to study the effect of PCS on haze pollution.

This article has the following 3 innovations. First, this article uses city-level data for the first time to study the effect of PCS on haze pollution. Second, data application innovation. Manually collect and sort out the city's PCS charging standards as an indicator of environmental regulation. We use Arcgis10.6 software to process PM$_{2.5}$ data from the Socioeconomic Data and Applications Center (SEDAC) of Columbia University to make up for the lack of PM$_{2.5}$ data at the city level (Wang et al., 2019) (8). Use city leader characteristic data to study the influence of local leaders on the environmental governance effect of PCS. Third, it is found that the experience of local leaders has a significant impact on the haze pollution effect of PCS.

The contents of other chapters of this article are arranged as follows. Chapter 2 introduces the current research status. Chapter 3 introduces the research methods and data. Chapter 4 gives the empirical results and result analysis. Chapter 5 concludes.

2. Literature review

At present, there are many literatures on the impact of PCS in China, but there are few studies on the impact of PCS on haze pollution. Based on the data of 30 provinces in China from 2011 to 2012, Guo et al. (2017) used structural equation model to empirically analyze the relationship between PCS and regional green growth performance (19). Zheng and Shi (2017) pointed out that PCS will promote the transfer of industries (17). Mendes and Georgina (2008) studied the role of environmental charges in reducing pollutant emissions from the air transport industry and pointed out its effectiveness (20). Li and Ramanathan (2018) research using China's provincial panel data found that PCS can only affect pollutant emissions during the year (21). Based on China's inter-provincial panel data from 2000 to 2012, Xie et al. (2017) empirical analysis found that the productivity driven by PCS is much stronger than the productivity effect produced by CCR (16). Ren et al. (2018) used the province's total pollution fee as an indicator of PCS (12). Empirical analysis found that in eastern China, the efficiency of PCS is higher than CCE and VR.

At present, there are many literatures on the effectiveness of environmental regulation on haze pollution control. However, most of the environmental regulations in these studies are CCR, and they are basically indicators of the intensity of environmental regulations constructed by the use of pollutant emissions and investment in the treatment of environmental pollution to represent environmental regulations. Based on panel data from 30 provinces in China from 2006 to 2016, Zhang et al. (2020b) used the proportion of investment in environmental pollution control to GDP as an indicator of environmental regulation, and conducted an empirical study using a spatial panel model (22). The results show that: from the standpoint of independence, environmental regulations play an important role in reducing haze pollution. Based on three indicators: the compliance rate of industrial wastewater discharge, the removal rate of industrial smoke and the comprehensive utilization rate of industrial solid waste, Zhou et al. (2019) construct comprehensive indicators of environmental
regulation. Subsequently, an empirical study based on urban panel data found that there is an inverted U-shaped relationship between PM 2.5 and the intensity of environmental regulations\(^{(1)}\). At the same time, Zhou et al. (2019) pointed out that green technological innovation and industrial structure optimization triggered by environmental regulations have also proved to be beneficial to reduce the harm of haze pollution\(^{(1)}\). Wang et al. (2019) used the differences-in-differences method (DID) to evaluate the effectiveness of the new ambient air quality standards (mainly PM\(_{2.5}\) monitoring)\(^{(8)}\). It was found that the new ambient air quality standard can improve the local environmental quality. Han and Li (2020) used China's provincial panel data to study the relationship between PM\(_{2.5}\) and 11 indicators such as gross domestic product per capita, tourism output value, and urbanization rate\(^{(14)}\). Zhang et al. (2019) pointed out that environmental regulations can effectively suppress haze pollution\(^{(9)}\).

We found that there is no research to empirically analyze the impact of PCS on haze pollution from the city level. Although, Zhang et al. (2020a) used the ratio of the total emission fee to the added value of the secondary industry as an indicator to empirically analyze the impact of PCS on haze pollution\(^{(15)}\). However, due to the unavailability of total city-level sewage charges data, research can only be conducted at the provincial level. In addition, the implementation of policies is largely influenced by the characteristics of local leaders. As far as we know, there is no literature considering the influence of local leaders on the PCS.

3. Empirical methodology and data

3.1. Empirical specification

Panel data can effectively alleviate the problem of missing variables. Secondly, the two dimensions of time and individual greatly increase the sample size, which can effectively improve the accuracy of estimation. Third, panel data can reflect the heterogeneity between individuals, that is, heterogeneous effects in time and space. This paper uses urban panel data for empirical research and constructs formula Eq.1.

\[
PM_{2.5it} = C + \alpha_i + \gamma_t + \theta PCS_{it} + \beta X_{it} + \epsilon_{it} \quad \text{(Eq.1)}
\]

where, \(PM_{2.5it}\) represents the PM\(_{2.5}\) concentration of city \(i\) in year \(t\); \(PCS_{it}\) represents the charging standard of PCS; \(X_{it}\) represents a series of control variables, including city control variables and weather control variables; the intercept term is \(C + \alpha_i + \epsilon_{it}\), where \(C\) is a constant. \(\alpha_i\) is the city fixed effect; \(\gamma_t\) is the year fixed effect; \(\epsilon_{it}\) is the error term.

There are generally three types of estimation methods for panel data regression models, namely, mixed effects regression models, fixed effects models and random effects models. The mixed effects model assumes that there are no significant individual effects and time effects in the panel data, that is, there are no significant differences between individuals. Therefore, the regression coefficient and intercept of the individual in the mixed effects regression model are the same. At this time, the form of the model is as Eq.2. The fixed effects model assumes that the panel data has individual effects. At this time, the formula form is as Eq.1. Random effects model, assuming that \(\alpha_i \sim N(0, \alpha_e)\), \(\gamma_t \sim N(0, \gamma_e)\), \(\epsilon_{it} \sim N(0, \epsilon_e)\), and \(\alpha_i\), \(\gamma_t\), \(\epsilon_{it}\) are not correlated with each other, and \(\alpha_i\) and \(\gamma_t\) are not correlated with explanatory variables. Assuming \(\nu_{it} = \alpha_i + \gamma_t + \epsilon_{it}\), the formula is Eq. 3.

\[
PM_{2.5it} = C + \theta PCS_{it} + \beta X_{it} + \epsilon_{it} \quad \text{(Eq.2)}
\]

\[
PM_{2.5it} = C + \theta PCS_{it} + \beta X_{it} + \nu_{it} \quad \text{(Eq.3)}
\]

We use the F test to choose the mixed model or the fixed effects model, and the Hausman test to decide whether to choose the fixed effects model or the random effects model.

3.2. Data

In order to study whether China's PCS can effectively reduce PM\(_{2.5}\) concentration, this paper uses the data of an imbalanced sample of 2080 Chinese cities from 2007 to 2015 for empirical analysis. The data mainly includes the following five aspects.
The data on urban employment, economic development, education, financial and transportation come from the China City Statistical Yearbook (3), as shown in Table 1. Chinese urban PM$_{2.5}$ emission data in 2007-2015 are collected from the Socioeconomic Data and Applications Center (SEDAC) of Columbia University (8). The data are sourced from the monthly data set of China’s surface climate data released by the National Meteorological Information Center (NMIC) in China. The local government leaders’ data including work experience in state-owned enterprises, work experience are selected from (22). We manually collected PCS charging standards from 2007 to 2015 to represent the sewage charging system (see Table 1).

### Table 1. Statistical description of variables.

| Classification                      | Variable               | Obs | Mean  | Std. Dev. | Min  | Max  | Unit | Description                                                                 |
|-------------------------------------|------------------------|-----|-------|-----------|------|------|------|----------------------------------------------------------------------------|
| Environmental Quality               | PM$_{2.5}$             | 3318| 37.1  | 16.4      | 2.8  | 91.0 | mg/m$^3$ | Haze concentration                                                          |
| Explanatory variables               | mayor_soe_exp          | 2187| 0.2   | 0.4       | 0    | 1    | 1    | Does the mayor have work experience in a state-owned enterprise             |
| City control Variable               | PCS                    | 3027| 0.8   | 0.4       | 0.2  | 10   | RMB/kg | Pollution charge system                                                    |
|                                    | HPT                    | 3318| 82/10 | 13748     | 100  | 286557| Million | Highway passenger traffic                                                  |
|                                    | FIP                    | 3318| 1.5   | 2.0       | 0.1  | 47.2 | Million | Financial industry practitioners                                           |
|                                    | PUB                    | 3318| 2.0   | 2.0       | 0.1  | 27.3 | Million | Practitioners in health, social security and social welfare industries      |
| Weather control variable           | BVL                    | 3318| 1.34E+07| 2.95E+07 | 2.81E+05| 4.89E+08| Ten thousand yuan | Balance of various RMB loans of financial institutions at the end of the year |
|                                    | OSS                    | 3318| 230.1 | 146.4     | 10   | 1564 | 1    | Number of ordinary secondary schools                                       |
|                                    | TCO                    | 3318| 4217.2| 8264.0    | 0    | 65230| 1    | Number of full-time teachers in ordinary colleges and universities         |
|                                    | WRE                    | 3318| 3297  | 648.0     | 0    | 9068 | 1    | Number of wholesale and retail enterprises above designated size (legal number) |
|                                    | ISE                    | 3318| 32556 | 124843    | 47   | 5168812| Ton | Industrial smoke (dust) emissions                                         |
|                                    | ALP                    | 3318| 9735  | 8426.2    | 0    | 9068 | 1    | Average local pressure                                                     |
|                                    | AWS                    | 3318| 148.0 | 51.2      | -21.5| 268.3| 0.1C | Average temperature                                                        |
|                                    |                       |     |       |           |      |      |      |                                                                            |

### 4. Results

#### 4.1. Main result

Table 2 summarizes the main results. Columns 1-3 are fixed effects models, and the fourth column is random effects models. Hausman test results show that the fixed effects model is more suitable for our model. Columns 1 show the results with time- and city-fixed effects, columns 2 also include weather control variables (i.e., atmospheric pressure, temperature, and wind speed), and in columns 3 we present our preferred specifications which further include city control variables. From the results of columns 1, 2, 3, and 4, all the coefficients of PCS are negative, indicating that PCS can effectively reduce the PM$_{2.5}$ concentration. Specifically, when the levy price of SO$_2$ emissions increases by 1 RMB/kg, the PM$_{2.5}$ concentration drops by 1.307 mg/m$^3$.

### Table 2. Main regression result.

|                             | (1)     | (2)     | (3)     | (4)     |
|-----------------------------|---------|---------|---------|---------|
| PCS                         | -0.438  | -0.432  | -1.307***| -1.830***|
|                             | (-1.56) | (-1.53) | (-3.57) | (-4.92) |
| City control Variable       | N       | N       | Y       | Y       |
| Weather control variable    | N       | Y       | Y       | Y       |
| Individual effect           | N       | N       | N       | N       |
| Time effect                 | Y       | Y       | Y       | N       |
| _cons                      | 39.00***| 32.67   | 41.67   | -99.51***|
|                             | (97.40) | (0.52)  | (0.66)  | (-8.29) |
| N                           | 2080    | 2080    | 2080    | 2080    |
| Groups                      | 255     | 255     | 255     | 255     |
4.2. Analysis of Heterogeneity of Economic Development Level

In order to study whether the PCS treatment effect on haze pollution is affected by the level of economic development, we rerun the regression using three subsamples: a low-income subsample, middle-income subsample, and high-income subsample. The results in Table 3 show that the lower the economic level, the better the effect of PCS on haze pollution. We believe that this is because regions with underdeveloped economies have a higher proportion of inefficient companies. And these low-efficiency companies are less able to withstand rising operating cost pressures. Therefore, in the face of PCS, these low-efficiency companies have to choose to shut down or reduce their production scale. Thereby achieving pollution reduction and environmental quality improvement.

Table 3. Regression results of economic level heterogeneity.

| Economic Level | Low     | Medium | High    |
|----------------|---------|--------|---------|
| PCS            | -1.824* | -1.736 | -1.604**|
|                | (-2.35) | (-1.58) | (-3.19) |
| City control Variable | Y | Y | Y |
| Weather control variable | Y | Y | Y |
| Individual effect | Y | Y | Y |
| Time effect | Y | Y | Y |
| _cons          | 377.6   | 12.71  | 71.92   |
|                | (1.76)  | (0.10) | (0.66)  |
| N              | 648     | 680    | 750     |

Note: ***, **, and * denote statistical significance at 0.1%, 1%, and 5% respectively and the values in parentheses represent t-statistics.

4.3. Analysis of Heterogeneity of Pollution Level

We divide the sample into nine quantiles based on the levels of PM$_{2.5}$ emissions and rerun the regressions for the subsamples using the quantile regression approach developed by Koenker and Bassett, (1978) and Roger et al., (1982)(23, 24). The quantile regression model is established as follows:

$$Q_q(\text{PM}_{2.5}|X) = \sum \beta_q X_q + \beta_q$$

(1)

where $X_i$ represents the influencing policy variables and control variables; $q$ indicates the quantiles, including 10$^{th}$, 20$^{th}$, ..., 90$^{th}$; and $\beta_q$ denotes the regression coefficient of the environmental governance effect of PCS at the $q_i$ quantile.

Wu et al. (2020) believe that the worse the environmental quality, the greater the pressure of the public and higher-level governments, the local governments will spend more efforts to manage environmental problems(25). However, inconsistent with Wu et al. (2020), the results in Table 4 show that the lower the concentration of PM$_{2.5}$, the better the effect of PCS on haze pollution(25). This may be because the better the environmental quality, the better the local environmental governance system. The better the local environmental governance system is, the more efficient the PCS as the MBR will be.
Table 4. Regression results of environmental quality heterogeneity.

| Quantile | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| PCS      | -2.342** | -2.265*** | -2.205*** | -2.159*** | -2.098*** | -2.042*** | -1.974*** | -1.906** | -1.806* |
|          | (-3.02) | (-3.66) | (-4.24) | (-4.62) | (-4.75) | (-4.35) | (-3.55) | (-2.80) | (-2.01) |
| City control variable | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Weather control variable | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| Individual effect | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| N | 2080 | 2080 | 2080 | 2080 | 2080 | 2080 | 2080 | 2080 | 2080 |

Note: ***, **, and * denote statistical significance at 0.1%, 1%, and 5% respectively and the values in parentheses represent t-statistics.

4.4. Mayor’s State-owned Enterprise Experience

In the official promotion championship, the Chinese national government gradually increased the assessment of local officials' environmental governance capabilities (26-28). In this part, we empirically analyze whether mayor_soe_exp will affect the governance effect of local PCS. The results in Table 5 show that the coefficient of PCS*mayor_soe_exp is negative. This means that in cities where the mayor has work experience in state-owned enterprises, PCS has a better effect on haze pollution. We think this is because the main target of PCS is enterprises, and mayors who have working experience in state-owned enterprises have a better understanding of the operating mechanism of enterprises and can implement PCS more efficiently.

Table 5. Regression results of the characteristics of local leaders.

| Variable | (1) | (2) | (3) | (4) |
|----------|-----|-----|-----|-----|
| PCS      | -1.408** | -2.96 | 0.238 | 0.88 |
|          | (-3.02) | (-2.40) | (2.33) | (0.88) |
| mayor_soe_exp | 1.758* | 1.310 | -1.706* | -1.209 |
|          | (2.33) | (1.70) | (-2.12) | (-1.46) |
| PCS*mayor_soe_exp | -1.042*** | -1.227* | 28.30 | 1999 |
|          | (-4.24) | (-2.51) | (35.26) | (0.44) |

Note: ***, **, and * denote statistical significance at 0.1%, 1%, and 5% respectively and the values in parentheses represent t-statistics.

5. Conclusions and discussion

This paper constructs panel data of 255 Chinese cities from 2007 to 2015. This article empirically analyzes the impact of PCS on PM<sub>2.5</sub>. At the same time, a heterogeneous analysis of the level of economic development, pollution level, and local leadership characteristics was carried out. There are the following four findings. First, when the levied price of SO<sub>2</sub> emissions increases by 1 RMB/kg, the PM<sub>2.5</sub> concentration drops by 1.307 mg/m<sup>3</sup>. Second, the lower the economic level, the better the effect of PCS on haze pollution. We think this is because the economic capacity of enterprises is relatively...
weak in areas with low economic development. In the face of increasing production costs, a large number of low-efficiency companies withdraw from the market, resulting in a reduction in pollutant emissions and haze pollution. Third, the lower the concentration of PM$_{2.5}$, the better the effect of PCS on haze pollution. This may be because the environmental governance system is more imperfect in the heavily polluted areas, and the efficiency of MBR is lower. Fourth, in cities where the mayor has work experience in a state-owned enterprise, PCS has a better effect on haze pollution.

Based on this, we propose the following suggestions.

First, PCS conducts regionally differentiated pricing. In economically underdeveloped areas, although the implementation of PCS can speed up the exit of low-efficiency enterprises, the exit of a large number of enterprises in the short term will bring employment and economic problems. In addition, in economically developed areas, companies are more able to withstand rising costs, and the efficiency of PCS is also lower. Therefore, pollution taxes should be priced regionally. Economically developed areas can appropriately increase the pollution tax rate; for economically underdeveloped areas, the tax rate can be appropriately reduced.

Second, for areas with severe haze pollution, priority should be given to improving the environmental policy system. Severe haze pollution often means that the regional environmental governance system is imperfect. In regions with imperfect policy systems, the efficiency of CCR is often higher than that of MBR. Therefore, for areas with more severe haze pollution, emphasis should be placed on strengthening the establishment of an environmental policy system, and CCR can also be implemented as a priority.

Third, in the process of implementing environmental policies, local leading groups should join members with corporate work experience. The implementation effect of environmental policies is largely affected by the characteristics of local leaders. The more the local leading group understands the operating mechanism of the enterprise, the more likely it is to implement policies based on the actual situation of the enterprise, especially the target of PCS is the enterprise.

Acknowledgements
The article is supported by the Fundamental Research Funds for the Central Universities in UIBE (Grant No. 19QD03), the National Social Science Foundation of China (Grant No. 18VDL017), and the Innovation Methods Special Foundation of the Chinese Ministry of Science and Technology (Grant No. 2018IMO40100). Certainly, all remaining errors are our own.

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