



# The effect of environmental regulation competition on haze pollution: evidence from China's province-level data

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**Abstract** Haze pollution has drawn lots of public concern due to its potential damages to human health. Strategic interaction of environmental regulation among local governments may lead to a race to the bottom and hinder air quality improvement. Still, current empirical evidence is scarce, especially from developing countries. Based on province-level panel data from 2004 to 2015, the paper employs a dynamic fixed effect spatial Durbin model to identify interactive patterns of environmental regulation and then investigate its environmental impact. Empirical results indicate that regional differences are observed in environmental regulation and haze pollution, and high-high and low-low clusters dominate the spatial pattern. Interactive patterns of economically similar provinces are dominated by strategic substitution, whereas provinces sharing common borders or belonging to the same region are dominated by

strategic complementation. Further, both race to the bottom and race to the top effect are discovered in the asymmetric test. The reaction coefficient values are much more extensive when competitors implement laxer policies, indicating a more significant racing trend to the bottom. Overall, after controlling for the spillover effect and hysteresis effect of haze pollution, the strategic interaction of environmental regulation among provinces is not conducive to improve air quality. The consequence might be correlated with low environmental standards, weak regulation enforcement, and the “free-ride” motive in China. These findings will be of great significance for optimizing local government behavior and improving air quality.

**Keywords** Environmental regulation · Strategic interaction · Haze pollution · Spatial panel model

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## Introduction

During the past 40 years, China has made remarkable economic achievements but confronts increasingly severe environmental problems (Jiang et al. 2019; Hao et al. 2018a). According to the report jointly released by Yale University, Columbia University, and the World Economic Forum in 2018, China's air quality ranked the fourth-lowest among 180 economies, making it one of the countries with the most severe

air pollution worldwide. Additionally, among the 338 prefecture-level cities monitored in China, only 11% met the WHO qualified standard ( $25 \mu\text{g}/\text{m}^3$ ) in 2015 (Hao et al. 2018b). Moreover, in 180 cities whose Air Quality Index (AQI) was over 100 in 2019, less than half of the cities met the expected targets (MEEPRC 2019). Haze pollution has become the biggest threat to public health and even sustainable economic development in China (Lelieveld et al. 2015; Li et al. 2019b; Sui et al. 2020; Hao et al. 2018a), arousing growing public awareness recently (Brauer et al. 2016; Zhu et al. 2020).

In response to public concern, the central government has carried out stringent environmental regulations to improve air quality since 2013. For instance, the “13th Five-Year” plan released in 2016 has officially made air quality targets mandatory for local governments for the first time, which means any sub-national governments who fail to meet the targets will be punished. Driven by these ambitious policies, there has been a gradual improvement of air quality since 2013 (Zhang et al. 2019). However, the expected goal of reducing air pollution has not been achieved yet (Hao et al. 2018b), thus resulting in heated debates about the effectiveness of environmental policies (Wu et al. 2019; Feng et al. 2020). Local governments responsible for the implementation of environmental policy are considered critical for air quality improvement. However, local governments’ environmental decisions are not made independently but are deeply influenced by vertical or horizontal level governments, namely, strategic interactions (Costa-Font et al. 2015; Wu et al. 2019). Evidence has revealed that the interactions may cause deviation from the socially optimal of regulation enforcement, engendering concerns about a race to the bottom or race to the top which predict a downward or upward bias in environmental policy, respectively (Levinson 2003; Millimet 2013; Lai 2019; Ge et al. 2020). Therefore, it is vital to substantially improve environmental quality to accurately identify local governments’ interaction patterns in environmental decision-making and evaluate its environmental impact.

Yet, the existing empirical evidence about environmental regulation competition mostly comes from US and European countries, relatively rare about China (Fredriksson and Millimet 2002; Revelli 2006; Chirinko and Wilson 2017; Galinato and Chouinard 2018). The direction and scale of interaction are

deeply affected by political incentives and institutional constraints (Costa-Font et al. 2015). We speculate that local Chinese officials may react differently under the peculiar decentralized governance structure. However, to our best knowledge, investigations about this regard are scarce. In China, the central governments exert top-down control over sub-national officials based on relative performance. Growth-oriented incentive makes local governments prioritize economic growth goals over other goals, especially environmental protection characterized by externality (van der Kamp et al. 2017; van Rooij et al. 2017). Hence, local officials have incentive race to relax environmental regulations in competition for mobile resources, leading to a race to the bottom (Lai 2019). Notably, faced with increasingly severe air pollution, reforms regarding the cadre assessment system have been addressed to induce local officials to pay more attention to environmental protection. Some scholars argue that the reforms have reshaped local officials’ behavior, transforming them from a race to the bottom to a race to the top (Peng 2020; Zhang et al. 2021). However, due to the heterogeneity of jurisdictions, it still needs an in-depth study about identifying strategic interaction and its environmental impact. This paper will first test the existence of strategic interaction in China based on province-level panel data from 2004 to 2015. Then examine whether the strategic interaction follows the asymmetric pattern suggested by the race to the bottom hypothesis and eventually investigates the environmental impact of environmental regulation competition.

The remainder of the paper is organized as follows. Firstly, the current literature on environmental regulation competition and its impact on environmental pollution are reviewed. Afterward, model specifications and variable selection are described. Finally, research results are discussed, and conclusions and policy implications are provided.

## Literature review

### Strategic interaction of environmental regulation among local governments

Strategic interaction refers to the phenomenon that policies in one jurisdiction are associated with neighboring jurisdictions (Costa-Font et al. 2015). Three

driving forces for strategic interaction behavior are emphasized (Millimet 2013). Firstly, transboundary pollution. Environmental issues with inter-regional spillover effect, for instance, air pollution, may provide more incentive for free-riding than local pollution (Kostka and Nahm 2017; Monogan et al. 2017; Feng et al. 2020). Secondly, resource competition. Environmental compliance cost is one of the prominent factors affecting capital flow, especially for pollution-intensive industries (Henderson 1996; Becker and Henderson 2000; Chung 2014; Yang et al. 2018). Those areas with less developed economies or tremendous fiscal stress are more inclined to treat environmental policies as instruments for capital competition (van Rooij et al. 2017; van der Kamp et al. 2017). Thirdly, yardstick competition. Voters may evaluate policymakers' performance through inter-jurisdictional comparisons, thus triggering local governments' imitative behavior (Besley and Case 1995). Notably, all three driving forces are empirically equivalent. Therefore, without more information, distinguishing among the underlying causes of strategic interaction will be difficult (Brueckner 2003; Millimet 2013). Preliminary exploration has been conducted in this aspect recently (Revelli 2006; Hayashi and Yamamoto 2016).

Additionally, the recognition regarding the behavior patterns has become a hot topic. Theoretically, there may exist two types of interactive behavior among local governments, including strategic complementation and strategic substitution (Brueckner and Saavedra 2001). The former indicates an upward sloping trend in the estimated reaction function; that is, a jurisdiction will strategically imitate its neighbor's environmental policies. Under the hypothesis of welfare maximization, most previous environmental federalism theories support the race to the top view, which insists that inter-jurisdictional economic competition may contribute to optimal environmental public goods (Tiebout 1956; Oates and Schwab 1988; Fredriksson and Millimet 2002). Using Reagan decentralization reform as a natural experiment, List and Gering (2000), Millimet (2003) and Millimet and List (2003) have indirectly proved the existence of a race to the top by comparing environmental quality changes before and after 1981. However, more recently, the race to the bottom hypothesis is emphasized, which argues that the assumption of welfare maximization is not always true, as local governments may make

decisions out of self-interest, such as political promotion. Consequently, local governments have incentives to relax environmental standards or weaken environmental enforcement in competition for a mobile resource, especially for those pollution-intensive industries that are perceived to be more sensitive to cost pressure but substantially contribute to local revenues (Woods 2006; Lai 2019; Deng et al. 2019). Furthermore, Konisky (2007) has emphasized the asymmetric effect of resource competition; that is, a region will respond only when neighbors' environmental regulations make it at a disadvantage in attracting capital.

The strategic substitution, which denotes a significantly negative reaction coefficient, has drawn more attention both theoretically and empirically. On the one hand, the spillover of public policy provides a strong incentive to "free ride"; for instance, local government tends to cut down its environmental expenditure as a response to a rise in that of its neighbors (Deng et al. 2012; Yu et al. 2013; Pan et al. 2020). On the other hand, some scholars argue that the substitution occurs when the income elasticity of environmental public goods is small relative to private goods, which indicates the trade-offs between economy and environment among local governments (Vrijburg and Mooij 2016; Chirinko and Wilson 2017).

#### The environmental impact of the environmental regulation competition

One of the preconditions to investigate the environmental impact of environmental regulation competition is that investment will respond to regulatory differences across jurisdictions (Levinson 2003). However, the conclusions are mixed. Early empirical studies did not find significant adverse effects of environmental regulation on capital flows (Jaffe et al. 1995). Until the late 1990s, more supportive evidence is found due to the improvement of estimation methods (Becker and Henderson 2000; Greenstone 2002; Shi and Xu 2018; Tian et al. 2020). Meanwhile, more attention has also been paid to the effect of environmental regulation on international capital flows, represented by the "pollution haven hypothesis." That is, the environmental compliance cost may weaken the competitiveness of pollution-intensive industries and force them to move to jurisdictions with

laxer environmental regulations (Chung 2014; Tang 2015; Yang et al. 2018; Zhang et al. 2020a). Therefore, driven by economic development, local officials, especially in less developed jurisdictions, may race to relax environmental policies in competition for capital, causing severe environmental degradation attributed to polluting industries' agglomeration (Liu et al. 2018).

However, some scholars argue that environmental regulation competition is conducive to the improvement of the environment. Firstly, the clean environment itself can be a competitive advantage that can help attract capital that favors a suitable environment (Konisky 2007; Zhang et al. 2021). Enterprises with more vital environmental capabilities or cleaner industries tend to invest more in jurisdictions with stricter environmental regulations (Bu and Wagner 2016; Rivera and Oh 2013). Hence, localities competing for mobile capital in nonpolluting industries such as those in the high-tech or service sector may race to provide better environmental amenities, and finally, promoting the improvement of the environment (van Rooij et al. 2017). Secondly, strict environmental policies are not always weakening the competitiveness of enterprises. Instead, in the long run, it may stimulate innovation and partially or wholly offset the compliance costs, namely, the Porter hypothesis (Porter and van der Linde 1995). In this case, enterprises may not be as sensitive to environmental compliance costs as we may expect, which to some extent, will weaken the motivation of trading environmental protection for economic development among jurisdictions, and eventually, achieving a win-win situation (Xie et al. 2017).

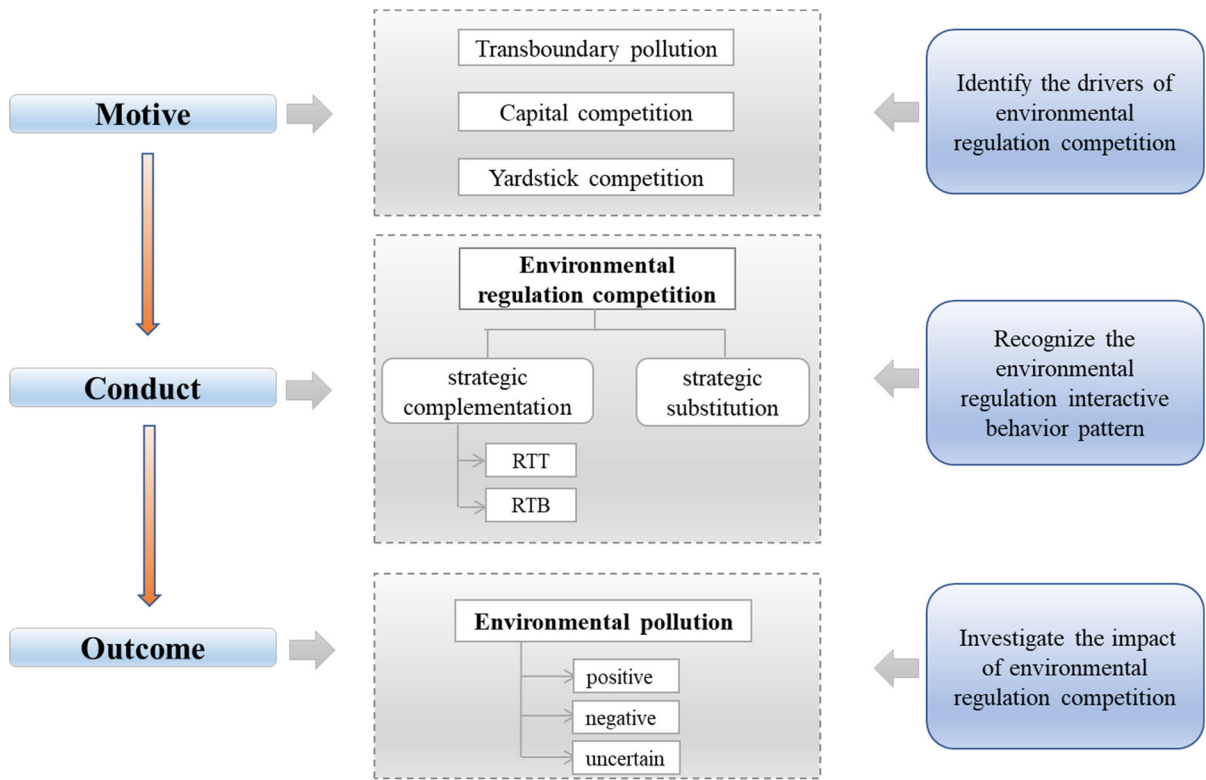
Besides, the environmental impact of environmental regulation competition may present uncertainty due to political incentives and institutional constraints (Costa-Font et al. 2015). Specific to China's case, growth-oriented mandates from the top have made sub-national governments prioritize economic over environmental goals, especially when faced with multiple tasks and limited financial resources (Kostka and Nahm 2017; Bai et al. 2019; van der Kamp et al. 2017). Local officials with excellent economic performance are more likely to be promoted, reinforcing the regional competition centered on economic development (Li and Zhou 2005; Yu et al. 2016). However, an environmental performance that is considered unimportant or not equally important to political

advancement is usually being ignored by local governments (Zheng et al. 2014). Consequently, the persistently insufficient environmental expenditure induced by political incentives has brought about unprecedented environmental degradation in China (Wu et al. 2013). In this case, China's central leadership has responded with ambitious efforts to recentralize environmental governance, such as building a mandatory target-based performance evaluation system, reinforcing central environmental supervision, implementing environmental protection admonishing talk policy. Most evidence has confirmed these reforms' effectiveness, resulting in significant environmental quality improvement (Chen et al. 2018; Zhang and Wu 2018, 2019; Peng 2020). However, some scholars argue that these reforms are only useful for specific pollutants and unable to achieve the overall emission reduction target (Wu et al. 2018). The structural framework of current research is illustrated in Fig. 1.

#### Literature commentary

In conclusion, literature about environmental regulation competition and its environmental effect has achieved fruitful results. However, some limitations still exist: (1) Evidence about the strategic behavior patterns is mixed. Most are from developed countries, yet investigations are relatively scarce referring to developing countries such as China. Considering the particularity of environmental governance structure and political promotion system, it is essential to complement empirical evidence about China. (2) Previous studies often treat environmental policies as decisions made independently by local governments and separately examine their environmental effects. The neglect of endeavor from neighboring jurisdictions may, to some extent, affect the validity of estimation results. (3) Current studies usually define neighbors or competitors in terms of geographic proximity or economic similarity, whereas less attention has been paid to the interaction within the same administrative region.

This study attempts to contribute from the following perspectives: (1) This paper verifies the existence of strategic interaction between local governments in environmental decision-making and further tests whether there is a race to the bottom or race to the top effect based on 30 provinces from 2004 to 2015 in



**Fig. 1** The structural framework of current research

China. Moreover, the environmental regulation intensity is based on governmental enforcement behavior other than the enterprise’s emission reduction behavior, which can better satisfy the research needs (Konisky and Woods 2012). (2) STIRPAT model and EKC hypothesis are incorporated to investigate the environmental impact of environmental regulation competition. The former is the classical model to examine socioeconomic factors affecting the environment, while the latter provides revisions by considering nonlinear economic development relations. (3) This paper expands the definition of neighbors or competitors into geographical proximity, economic similarity, and regional proximity to enrich existing results.

**Model specification, variables, and data**

Model specification

Three models are specified in our study. The first one aims to verify the existence of strategic interaction. Based on this model, the second one is designed to test the asymmetric effects of strategic interaction further, determining whether the race to the bottom or race to the top hypothesis is supported. Eventually, the STIRPAT model and EKC hypothesis are incorporated to investigate the environmental impact of environmental regulation competition.

Strategic interaction model

Following Brueckner (2003) and Fredriksson and Millimet (2002), a spatial econometric model is designed to test for the presence of strategic interaction among provinces in China. This approach models a region’s behavior as a function of its neighbors’ behaviors. The specification is as follows:

$$reg_{it} = \rho \sum_{j=1}^n w_{ij} \times reg_{jt} + \beta X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \quad (1)$$

$$i = 1, \dots, n, j \neq i$$

where index  $i, j$  is for the cross-sectional dimension (provinces in our sample),  $t$  is for the time dimension,  $n$  is for the number of provinces,  $reg_{it}$  is a measure of environmental regulation intensity in province  $i$  at time  $t$ ,  $w_{ij}$  represents elements of spatial weight matrix which describes the importance of province  $j$  to province  $i$ ,  $reg_{jt}$  measures the environmental regulation intensity in province  $j$  at time  $t$ ,  $\sum w_{ij} \times reg_{jt}$  is the spatially lagged dependent variable. It represents a weighted average of competitors' environmental regulation.  $X_{it}$  is a vector of province characteristics,  $\mu_i$  is province fixed effects which are used to control for time-invariant regional heterogeneity,  $\sigma_t$  is year fixed effects, and  $\varepsilon_{it}$  is the random error term.  $\rho$  is the spatial autoregressive coefficient that we are focusing on, where a nonzero coefficient suggests that there is strategic interaction. In detail, a statistically significant, positive  $\rho$  implies that the province will imitate the regulatory behavior of competitors, indicating there's strategic complementation. In contrast, a statistically significant, negative  $\rho$  implies a strategic substitution.

#### Asymmetric effects model

Based on Konisky (2007), we estimate two additional models to test if there's a race to the bottom or race to the top. Under the hypothesis of resource competition, the strategic interaction may only occur when competitors' environmental regulation makes it at a disadvantage in attracting capital. The specification is as follows:

$$reg_{it} = \lambda_1 D_{it} \sum_{j \neq i} w_{ij} \times reg_{jt} + \lambda_2 (1 - D_{it}) \sum_{j \neq i} w_{ij} \times reg_{jt} + \beta X_{it} + \mu_i + \sigma_t + \varepsilon_{it}$$

$$i = 1, \dots, n \quad (2)$$

where,

$$D_{it} = \begin{cases} 1, & \sum_{j \neq i} w_{ij} \times reg_{jt} < \sum_{j \neq i} w_{ij} \times reg_{jt-1} \\ 0, & \text{otherwise} \end{cases}$$

$$reg_{it} = \lambda_1 I_{it} \sum_{j \neq i} w_{ij} \times reg_{jt} + \lambda_2 (1 - I_{it}) \sum_{j \neq i} w_{ij} \times reg_{jt} + \beta X_{it} + \mu_i + \sigma_t + \varepsilon_{it}$$

$$i = 1, \dots, n \quad (3)$$

where,

$$I_{it} = \begin{cases} 1, & reg_{it} > \sum_{j \neq i} w_{ij} \times reg_{jt} \\ 0, & \text{otherwise} \end{cases}$$

Equation (2) considers whether strategic interaction occurs when competitors' environmental regulation intensity this year is less than that in the prior year. To be more specific, the strategic interaction effect is given by  $\lambda_1$ , when the weighted average of competitors' environmental regulation effort is less than the previous year; otherwise, the effect is given by  $\lambda_2$ . Equation (3) considers whether strategic interaction occurs when competitors' environmental regulation intensity is lower than its own. The strategic interaction effect is given by  $\lambda_1$ , when competitors' environmental regulation is lower than its own; otherwise, the strategic interaction effect is given by  $\lambda_2$ . When  $\lambda_1 > 0$  and  $\lambda_2$  is not significantly different from zero, indicating there's a race to the bottom effect; when  $\lambda_1 > 0$  and  $\lambda_2 > 0$ , indicate that both race to the bottom and race to the top effect exist; when  $\lambda_2 > 0$ , and  $\lambda_1$  is not significantly different from zero, indicating there's a race to the top effect.

#### Environmental impact model

IPAT model, proposed by Ehrlich and Holdren (1971), has been widely applied in the impact of environmental pollution research. The model is specified as,  $I = P \times A \times T$ , where  $I$ ,  $P$ ,  $A$ ,  $T$  represent the environmental pressure, population, economic development level, and technical level. Nevertheless, the linear equivalence between the variables is not consistent with reality. Therefore, Dietz and Rosa (1994) created the STIRPAT model by modifying the IPAT model and further incorporated the random term



to satisfy the empirical analysis. Specifically, the basic STIRPAT model is:  $I_{it} = \alpha \times P_{it}^\theta \times A_{it}^\gamma \times T_{it}^\varphi \times \varepsilon_{it}$ , where  $i$  denotes region,  $t$  denotes time,  $\alpha$  represents the constant term,  $\theta, \gamma, \varphi$  are estimated parameters of  $P, A$  and  $T$ , respectively, and  $\varepsilon_{it}$  is the random error term. The EKC hypothesis proposed by Grossman and Krueger (1991) is also regarded as the basic theoretical framework to study the impact of environmental pollution. An inverted U-shaped relationship between economic development and pollution was found. Moreover, local and competitors' environmental regulations are also added to the model to investigate the environmental impact of environmental regulation competition. The specification is as follows:

$$\begin{aligned} \ln HP_{it} = & \alpha_0 + \theta \ln pop_{it} + \gamma_1 \ln pgdp_{it} \\ & + \gamma_2 (\ln pgdp_{it})^2 + \varphi \ln tech_{it} + \beta_1 reg_{it} \\ & + \beta_2 \sum_{j=1}^n w_{ij} \times reg_{jt} + \delta X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \\ & i = 1, \dots, n \end{aligned} \tag{4}$$

where  $HP, pop, pgdp, tech$  denote the environmental pressure ( $I$ ), population ( $P$ ), economic development level ( $A$ ), and technical level ( $T$ ), respectively. Furthermore, the spillover effect and hysteresis effect of haze pollution are emphasized in previous studies. Under this circumstance, the traditional panel model is no longer suitable. Therefore, we further expand the model into a dynamic spatial panel model such as SAR, SEM, and SDM. The SAR model is constructed as in Eq. (5):

$$\begin{aligned} \ln HP_{it} = & \alpha_0 + \lambda \ln HP_{it-1} + \rho \sum_{j=1}^n w_{ij} \times \ln HP_{jt} + \theta \ln pop_{it} \\ & + \gamma_1 \ln pgdp_{it} + \gamma_2 (\ln pgdp_{it})^2 \\ & + \varphi \ln tech_{it} + \beta_1 reg_{it} + \delta X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \\ & i = 1, \dots, n \end{aligned} \tag{5}$$

where,  $\ln HP_{it-1}$  indicates the haze pollution level of the previous year. The significant positive coefficient  $\lambda$  suggests the existence of the hysteresis effect.  $\rho$  indicates the weighted average of haze pollution in neighbor areas, reflecting the spillover effect of haze pollution.

The spatial error models are constructed as in (6) and (7):

$$\begin{aligned} \ln HP_{it} = & \alpha_0 + \lambda \ln HP_{it-1} + \theta \ln pop_{it} + \gamma_1 \ln pgdp_{it} \\ & + \gamma_2 (\ln pgdp_{it})^2 + \varphi \ln tech_{it} \\ & + \beta_1 reg_{it} + \delta X_{it} + \mu_i + \sigma_t + \varepsilon_{it} \\ & i = 1, \dots, n \end{aligned} \tag{6}$$

$$\varepsilon_{it} = \delta \sum_{j=1}^n w_{ij} \times \varepsilon_{jt} + \zeta_{it} \tag{7}$$

The spatial Durbin models are constructed as in (8):

$$\begin{aligned} \ln HP_{it} = & \alpha_0 + \lambda \ln HP_{it-1} + \rho \sum_{j=1}^n w_{ij} \times \ln HP_{jt} \\ & + \theta \ln pop_{it} + \gamma_1 \ln pgdp_{it} + \gamma_2 (\ln pgdp_{it})^2 \\ & + \varphi \ln tech_{it} + \beta_1 reg_{it} + \delta X_{it} \\ & + \alpha_1 \sum_{j=1}^n w_{ij} \times \ln pop_{jt} + \alpha_2 \sum_{j=1}^n w_{ij} \times \ln pgdp_{jt} \\ & + \alpha_3 \sum_{j=1}^n w_{ij} \times (\ln pgdp_{it})^2 \\ & + \alpha_4 \sum_{j=1}^n w_{ij} \times \ln tech_{jt} + \alpha_5 \sum_{j=1}^n w_{ij} \times \ln reg_{jt} \\ & + \alpha_6 \sum_{j=1}^n w_{ij} \times X_{jt} + \mu_i + \sigma_t + \varepsilon_{it} \quad i = 1, \dots, n \end{aligned} \tag{8}$$

### Spatial weight matrix

The spatial weight matrix is constructed to assign relative importance to competitors. Three types of spatial weight matrix are geographical weight matrix, economic weight matrix, and regional weight matrix. The first one is based on geographical proximity, denoted by  $W^{border}$  and  $W^{distance}$ . The former indicates that if two provinces share the common border, then the elements  $w_{ij} = 1$ , otherwise  $w_{ij} = 0$ . The latter suggests that the closer the two provinces are, the greater the spatial weights will be. Concretely, the elements  $w_{ij} = 1/d_{ij}$  in  $W^{distance}$ , where  $d_{ij}$  represents the inverse of centroid distance among provinces, calculated by GeoDa software. Secondly, economic proximity, denoted by  $W^{eco}$  and  $W^{eco*border}$ .  $W^{eco}$  treats all the provinces as its neighbors and uses the gap of

average GDP per capita to assign relative weights. The elements  $w_{ij} = 1/|pgdp_i - pgdp_j|$ , which means that the provinces with similar economic development will be assigned larger weights. However,  $W^{eco*border}$  takes both economic proximity and geographical proximity into account, suggesting that if two provinces are economic close whereas not geographical close, the importance of spatial weights will be weakened. Therefore, the elements  $w_{ij} = 1/|pgdp_i - pgdp_j|$  if the two provinces share a common border; otherwise,  $w_{ij} = 0$ . Thirdly, regional proximity, denoted by  $W^{region}$  and  $W^{region*eco}$ . According to the China National Bureau of Statistics, China's economic regions can be divided into Eastern, Central, Western, and Northeastern, including 10 provinces, 6 provinces, 12 provinces and 3 provinces, respectively.  $W^{region}$  indicates that if the two provinces belong to the same region, then the elements  $w_{ij} = 1$ ; otherwise,  $w_{ij} = 0$ .  $W^{region*eco}$  take both economic proximity and regional proximity into account; that is, if two provinces belong to the same region, the elements  $w_{ij} = 1/|pgdp_i - pgdp_j|$ ; otherwise,  $w_{ij} = 0$ . All spatial weight matrix is row-normalized. Table 1 presents details about the setting of the spatial weight matrix.

#### Variable selection

#### Explained variable

Haze pollution (*lnHP*).  $PM_{2.5}$  and  $PM_{10}$  are regarded as the primary pollutants causing haze pollution in

China. However, there are few official data on  $PM_{2.5}$  concentrations before 2013. Hence, in this paper, the average annual concentration of  $PM_{10}$  is employed as the proxy of haze pollution. The National Bureau of Statistics has been collecting  $PM_{10}$  concentration data since 2003, which provides good continuity and can meet this paper's research needs.

#### Key explanatory variable

Environmental regulation intensity (*lnERS*). As the interactive behavior mainly takes place among local governments, thus the optimal indicator will be the one that accurately reflects governmental behavior (Konisky and Woods 2012). Pollution levies are regarded as the proper proxy variable of environmental regulation intensity for two reasons. Firstly, the central government confirms the interval of pollution levies; however, the local governments are free to choose standards within the interval. Secondly, the enforcement of pollution levies varies considerably among regions, which can better reflect the environmental regulation intensity. Nevertheless, various factors may affect pollution levies, i.e., resource endowment, industrial structure, and emission reduction technologies, leading to biased results if no adjustments are made. In this study, pollution levies per pollution emission are employed to measure the intensity of environmental regulation. However, the pollutants are unable to sum up due to their different dimensions and possible multicollinearity. Therefore,

**Table 1** The setting of the spatial weight matrix

Type	Name	Description	Properties
Geographical proximity matrix	$W^{border}$	$w_{ij} = 1$ , if two provinces share the common border, otherwise, $w_{ij} = 0$	Time invariant
	$W^{distance}$	$w_{ij} = 1/d_{ij}$ , $d_{ij}$ represents the inverse distance of centroid distance among each province	Time invariant
Economic proximity matrix	$W^{eco}$	$w_{ij} = 1/ pgdp_i - pgdp_j $ , $pgdp$ indicates the average per GDP of each province	Time variant
	$W^{eco*border}$	$w_{ij} = 1/ pgdp_i - pgdp_j $ , if two provinces share the common border; otherwise, $w_{ij} = 0$	Time variant
Regional proximity matrix	$W^{region}$	$w_{ij} = 1$ , if two provinces belong to the same region; otherwise, $w_{ij} = 0$	Time invariant
	$W^{region*eco}$	$w_{ij} = 1/ pgdp_i - pgdp_j $ , if two provinces belong to the same region; otherwise, $w_{ij} = 0$	Time variant



we construct a pollution emission index (*PEI*), including wastewater, sulfur dioxide, and dust. The specification is as follows:

$$PX_{it} = p_{ik} \sqrt{\frac{1}{n} \sum_{j=1}^n p_{jk}}, k = 1, 2, 3 \tag{9}$$

where, index *i, j* is for the province, *t* is for the year, *k* is for the type of pollutant, *n* is for the number of provinces, *p<sub>ik</sub>* represents emission per unit of real GDP in province *i* in *k* pollutant. *PX<sub>it</sub>* is the *PEI* of each pollutant indicator. Then we calculate the mean value of three pollutants indexes denoted by *PX<sub>i</sub>*. The larger the value of *PX<sub>i</sub>* is, the higher the province’s *PEI* will be.

$$PX_i = \frac{(PX_{1i} + PX_{2i} + PX_{3i})}{3} \tag{10}$$

*Control variables*

The control variables are as follows. Since no evidence has proved that the transportation status and weather conditions are related to environmental regulation intensity; therefore, in the strategic interaction model, the two variables *lcar* and *rain* are not included.

Economic development (*lpgdp, lpgdp2*). Based on the STIRPAT model and EKC hypothesis, economic development has a significant impact on environmental pollution. The demand for environmental quality varies in different stages of development, affecting environmental regulation intensity. In this paper, following Liu et al. (2020) and Li et al. (2019b), the logarithm of per capita GDP and its quadratic term are employed to measure economic development.

Population density (*lpop*). The expansion of population in urban areas will lead to an increase in consumption, which, in turn, aggravate pollution. Besides, areas with larger populations may face tremendous public pressure, forcing the local governments to put more effort into environmental governance. Following Liu and Dong (2019), a population density indicator is applied in this paper, calculated as the total population divided by the urban area.

Technical innovation (*itech*). Technical capacity, especially the progress of emission reduction technology, will increase energy use efficiency and mitigate environmental pollution (Dong et al. 2019). In this

paper, we mainly emphasize the performance of pollution reduction and measure it by energy consumption per unit of GDP. The smaller the value of this indicator, the higher the technical capacity.

Industrial structure (*industry*). The industrial sector, especially those high coal-consumption industries, does almost four times as much damage to air quality as the service sector. Following Liu et al. (2018), we use the ratio of industrial added value to GDP to measure the industrial structure.

Economic openness (*fdi*). The pollution haven hypothesis indicates that developed countries will transfer pollution-intensive industries to developing countries with laxer environmental control and treat them as a pollution haven. However, the pollution halo hypothesis affirms that the technology spillover of FDI will improve the host country’s environment. We use the percentage of foreign investment to GDP to measure economic openness.

Energy mix (*energy*). The mix of energy consumption is also an essential driving factor in haze pollution. Compared to clean energy regions, pollution may worsen in areas where fossil energy consumption is high. In this paper, the ratio of coal consumption to total energy consumption is employed to measure the energy mix.

Fiscal decentralization (*budget*). Fiscal decentralization reflects local governments’ discretion in decision-making, which is regarded as the institutional factor affecting environmental pollution (Hong et al. 2019). Meanwhile, regions with more fiscal decentralization are more likely to change behavior in the direction of central incentives. The ratio of per capita local fiscal expenditure to per capita central fiscal expenditure is used to measure fiscal decentralization.

Public participation (*public*). Pressure from the public may force local governments to enforce stricter environmental policies. Meanwhile, urban residents’ haze reduction behavior contributes significantly to pollution control (Shi et al. 2020). The number of proposals per 10,000 people from the Chinese People’s Political Consultative Conference (CPPCC) proposals and the National People’s Congress (NPC) is employed to measure public pressure.

Structure of ownership (*nation*). Regions with a high proportion of state-owned enterprises may have more substantial bargaining power over local government decisions (Wang et al. 2003). In our study, the ratio of state-owned enterprises’ employees to the total

number of employees is used to measure ownership structure.

Transportation (*lcar*). Vehicle exhaust emission is an essential source of haze pollution. Due to the traffic congestion and incomplete combustion of fuel, regions with a high penetration rate of automobiles usually face severe haze pollution (Sun et al. 2018). In this paper, we use the number of civil cars per thousand people to measure traffic conditions.

Weather conditions (*rain*). Besides anthropogenic emissions, haze pollution will also be affected by weather conditions, including temperature, precipitation, humidity, wind speed, etc. To avoid the multicollinearity problem, we employ the average annual rainfall to measure weather conditions.

#### Data sources and descriptive statistics

Based on data availability, this paper uses panel data of 30 provinces in China (except for Hong Kong, Macao, Taiwan, and Tibet) from 2004 to 2015. All nominal variables are deflated to the constant 1996 price. The foreign exchange data are converted to RMB according to the average annual exchange rate collected from China Foreign Trade Statistical Yearbook. All relevant data can be obtained from the China Statistical Yearbook, China Environmental Yearbook, China Energy Statistical Yearbook, China Industry Economy Statistical Yearbook, and each province's Statistical Yearbook. Table 2 presents sources, definitions, and descriptive statistics of variables in details.

## Results and discussion

### Regional distribution and spatial analysis of environmental regulation and haze pollution

This section illustrates the regional distribution of environmental regulation and haze pollution from a static perspective. Afterward, the exploratory spatial data analysis (ESDA) approach is applied to investigate the spatial agglomeration trend from a dynamic perspective.

### Regional distribution of environmental regulation and haze pollution

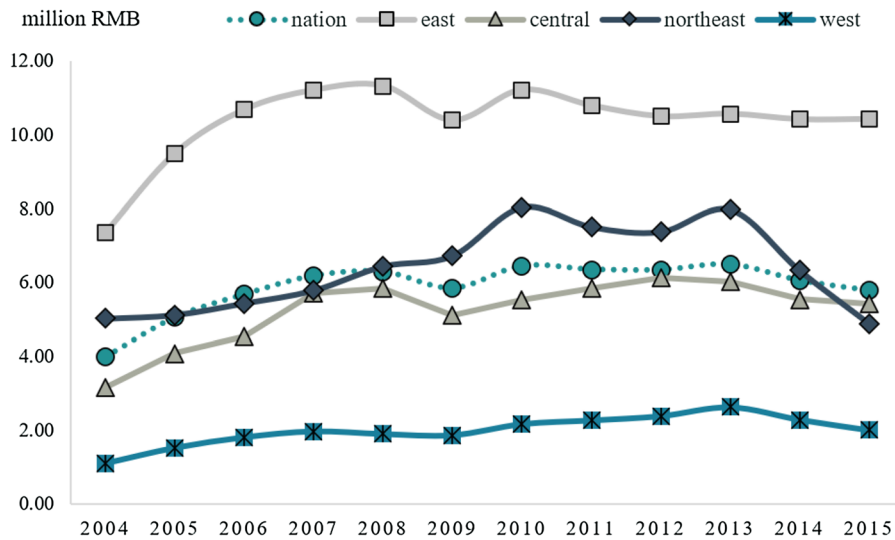
As is illustrated in Fig. 2, from 2004 to 2015, the value of annual average environmental regulation intensity has increased steadily from 4 million to 5.79 million RMB nationwide. However, it reveals significant regional differences among eastern, central, north-east, and western regions. Specifically, the eastern region has the strictest environmental policies, ranging from 7.37 million to 10.44 million RMB from 2004 to 2015, followed by the north-east, central, and western regions. Additionally, the environmental regulation intensity has dynamically changed over time. It had remained steadily increased before 2009. However, due to the financial crisis since 2008, it dropped to the bottom except for the north-east region. Afterward, the rapid growth has sustained in the north-east region between 2009 and 2013. This change may be related to the North-east Revitalization Strategy proposed by former Premier Wen Jiabao since 2004. Driven by the massive expansion of heavy industries, pollution levies per emission have risen sharply but dropped down dramatically since 2013, reflecting the economic recession in recent years. Contrary to that, the environmental regulation intensity of the other three regions has been stable after 2009.

As is shown in Fig. 3a, the environmental regulation intensity has varied among provinces. Following the conclusion drawn from Fig. 2, provinces in the east have witnessed the strictest environmental policy, including Shandong, Jiangsu, Shanghai, Guangdong, etc. Except for Jiangxi province, most central provinces are with similar environmental regulation intensity. As for north-east regions, Liaoning has ranked first, followed by Heilongjiang and Jilin. The western provinces, such as Guizhou, Gansu, Ningxia, Qinghai, and Xinjiang, have the most relaxed environmental policy relative to other regions. Figure 3b has illustrated the regional distribution of the annual average of PM<sub>10</sub> from 2004 to 2015. It reveals that haze pollution has spread across the whole nation, especially in north Yangtze River, with Shandong, Hebei, Beijing, Shaanxi, Ningxia, Gansu, and Xinjiang the most polluted areas (Li et al. 2019a). Combined with the results drawn from Fig. 3a, we can figure out that even eastern provinces have

**Table 2** Data sources and descriptive statistics of variables

Variables	Definition	Mean	S.D	Min	Max	Sources
lnHP	Log average annual concentration of PM <sub>10</sub>	1.999	0.133	1.519	2.484	CSY
lnERS	Pollution levies per pollution emission	2.536	0.512	0.848	3.511	CSY, CEY
lpgdp	Log per capital GDP	0.680	0.595	-0.993	2.044	CSY
lpgdp2	Quadratic term of GDP per capital	0.815	0.907	0.000	4.179	CSY
lpop	Log population per square kilometer	5.419	1.264	2.013	8.250	CSY
ltech	Energy consumption per unit of GDP	0.143	0.223	-0.240	0.746	CESY
industry	The ratio of industrial added value to GDP	0.404	0.081	0.131	0.592	CSY
fdi	The ratio of FDI to GDP	0.027	0.020	0.001	0.083	CSY
energy	The ratio of coal consumption to total energy consumption	0.691	0.272	0.121	1.813	CESY
budget	The ratio of per capita local fiscal expenditure to per capita central fiscal expenditure	5.297	2.916	1.491	14.600	CSY
public	The number of CPPCC proposals and NPC proposals per 10,000 people	0.109	0.074	0.000	0.724	CSY
nation	The proportion of state-owned enterprises	0.149	0.062	0.026	0.338	CIESY
lcar	Log the number of civil cars per thousand people	1.694	0.321	0.869	2.392	CSY
rain	Log the average annual precipitation	2.872	0.278	1.874	3.420	CSY

CSY denotes China Statistical Yearbook, CEY denotes China Environmental Yearbook, CESY denotes China Energy Statistical Yearbook, CIESY denotes China Industry Economy Statistical Yearbook

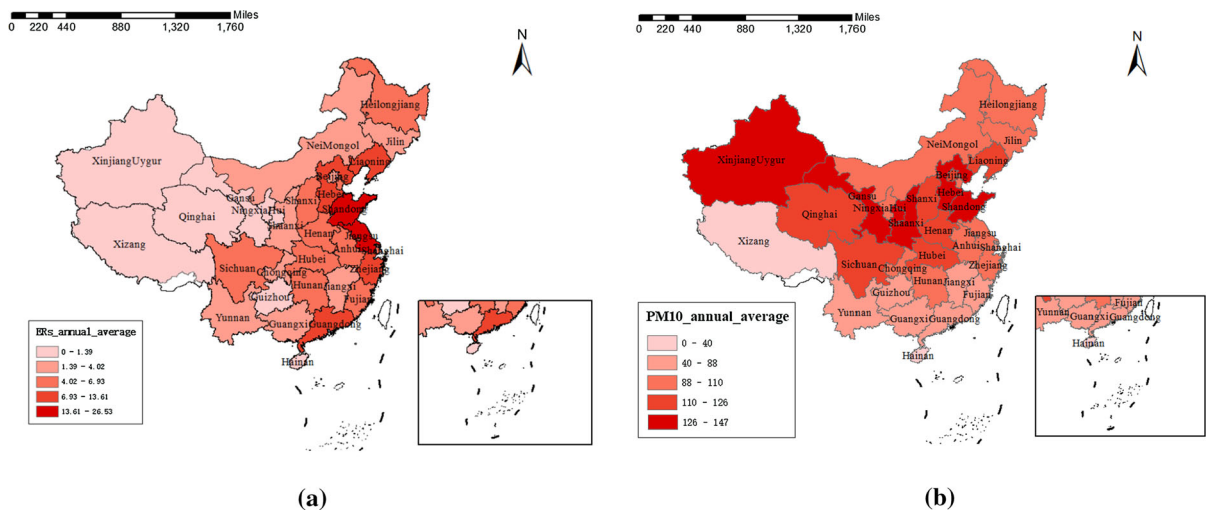


**Fig. 2** Annual average of environmental regulation intensity from 2004 to 2015

implemented the strictest environmental policy, the pollution has not been alleviated accordingly. The question that arises is whether the environmental policy is effective or not in haze control. If not, it's because environmental standards are too lax or environmental policies are poorly enforced.

### Spatial analysis of environmental regulation and haze pollution

The ESDA approach is applied to detect the spatial association of environmental regulation and haze pollution. More specifically, Global Spatial



**Fig. 3** **a** Distribution of annual average of environmental regulation intensity from 2004 to 2015; **b** Distribution of annual average of  $PM_{10}$  from 2004 to 2015

Autocorrelation (GSA) is a measure of overall clustering, and Moran's  $I$  is the commonly used statistic that can be visualized as Moran Scatter Plot (MSP) (Anselin et al. 2007). The observations are categorized into four types of spatial autocorrelation patterns, including high-high (upper right), low-low (lower left), low-high (upper-left), and high-low (lower right), respectively. The first two types indicate that values are surrounded by similar neighbors, whereas the last two suggest potential spatial outliers, that is, values surrounded by dissimilar neighbors. The Local Indicator of Spatial Association (LISA) provides a means to figure out the significant local cluster and visualize them to a special LISA Cluster map. All spatial data analysis is done using GeoDa software.

As is shown in Table 3, the observed Moran's  $I$  values of environmental regulation intensity have ranged from 0.1786 to 0.3156 from 2004 to 2015, suggesting a strong positive spatial autocorrelation. Similarly, haze pollution also presents a significantly positive trend, ranging from 0.1397 to 0.5992. Figure 4 illustrates that environmental regulation and haze pollution observations are concentrated in the first and third quadrants, suggesting that high-high and low-low spatial patterns are dominated. LISA Cluster map in Fig. 5 indicates that local environmental regulation clusters are relatively stable over time; however, local haze pollution clusters are growing in spatial extent, implying a higher degree of spatial agglomeration. For example, the number of provinces in the high-high

**Table 3** Global Moran's  $I$  value of environmental regulation and haze pollution

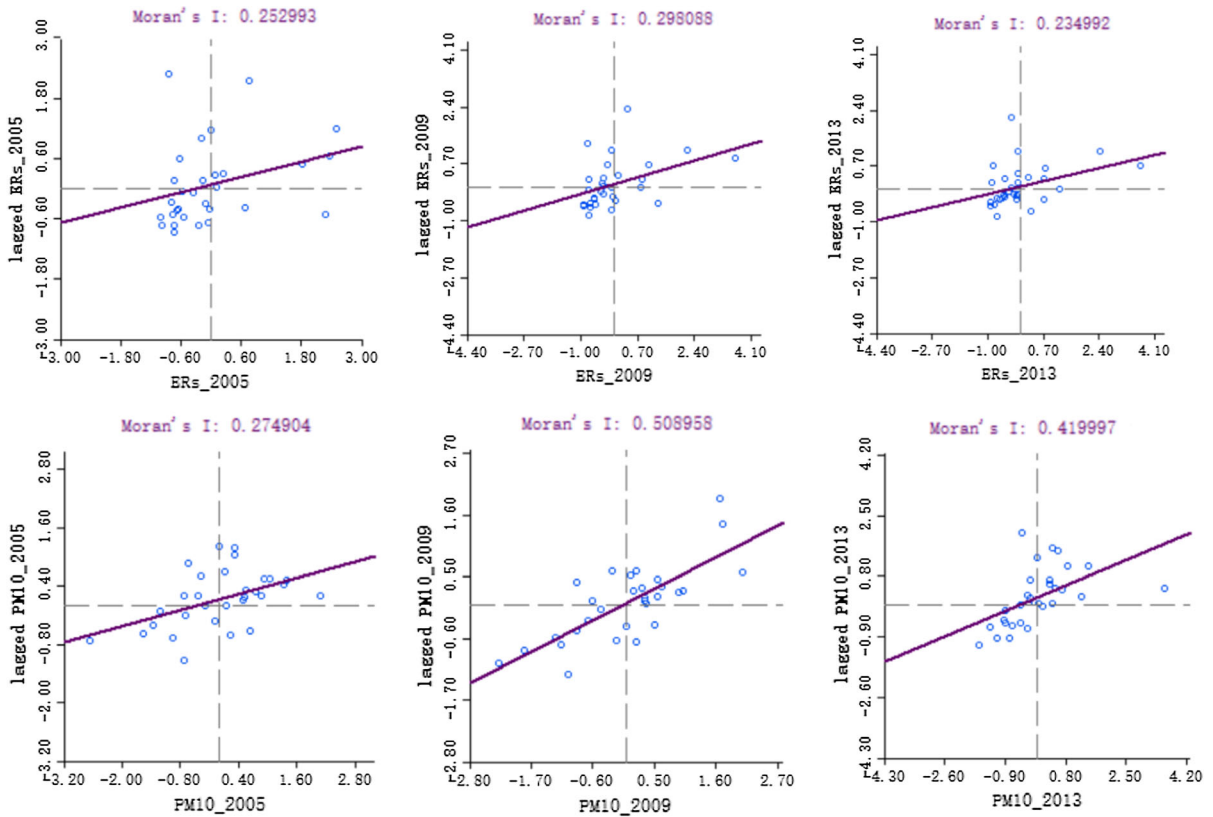
year	Environmental regulation		Haze pollution	
	Moran's $I$	z-value	Moran's $I$	z-value
2004	0.1786*	1.7851	0.1397*	1.3732
2005	0.2530**	2.4925	0.2749***	2.4893
2006	0.2500**	2.4317	0.4667***	4.2330
2007	0.3134***	2.9821	0.3692***	3.4880
2008	0.3156***	2.9924	0.3632***	3.1110
2009	0.2981**	2.8298	0.5090***	4.2967
2010	0.2590**	2.6098	0.4632***	4.0922
2011	0.2495**	2.6851	0.4576***	3.9687
2012	0.2533**	2.5652	0.4748***	4.4142
2013	0.2350**	2.3495	0.4200***	3.9842
2014	0.2610**	2.6738	0.5948***	5.1487
2015	0.3086***	3.0251	0.5992***	5.1995

\*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively

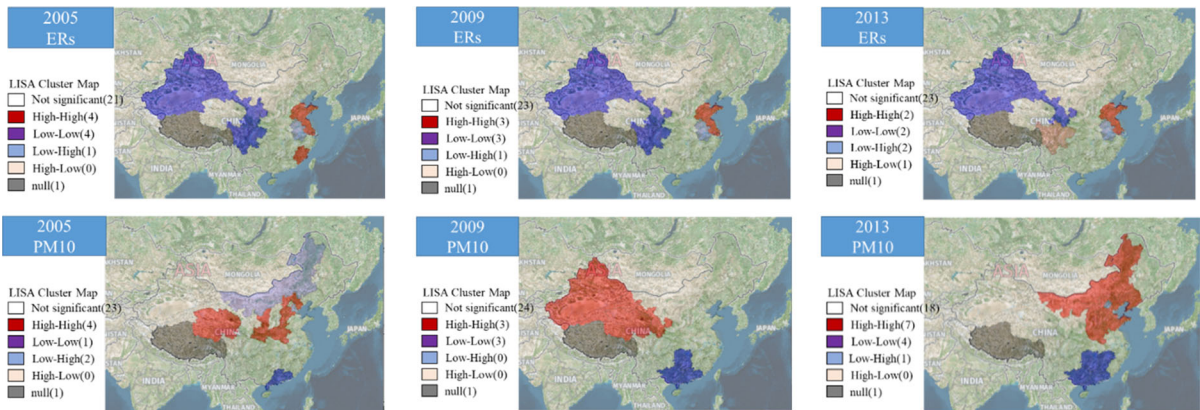
spatial pattern has increased from 4 to 7 in 2005 and 2013, forming a large cluster in northern China, consistent with current haze pollution distribution.

#### Strategic interaction of environmental regulation

Before estimating model (1), one issue concerning the endogeneity of environmental regulation needs to be



**Fig. 4** MSP of environmental regulation and haze pollution in China of year 2005, 2009, and 2013



**Fig. 5** LISA Cluster maps of environmental regulation and haze pollution in China of year 2005, 2009, and 2013

dealt with first. Actually,  $\sum w_{ij} \times reg_{jt}$  is endogenous because of simultaneous causation regarding  $reg_{it}$ , which means if there is strategic interaction, the provinces will make decisions simultaneously. In this case, the OLS estimator will be biased. Two methods have been developed to solve this problem. One is a

maximum likelihood (ML) estimator proposed by Anselin (1988), and the other is a two-stage least squared instrumental variables (2SLS-IV) method proposed by Kelejian and Prucha (1998). It's worth noting that the ML estimator requires a normal distribution of error terms; otherwise, the estimation



will be biased. Whereas, the 2SLS-IV approach does not impose restrictions about the normal distribution hypothesis; it can even provide consistent estimation in the presence of spatial-error dependence (Kelejian and Prucha 1998). In our study, following Konisky (2007), 2SLS-IV method is applied with all explanatory variables and their spatial lag terms as our IV instruments.

Additionally, some tests need to be conducted before performing the estimation results. Skewness/Kurtosis tests for normality indicate that most variables except the *nation* are strongly abnormal, meaning that the IV estimator is more effective than the ML estimator. Hausman test suggests that models with fixed effects are preferred. Kleibergen–Paap rk LM test indicates that we can reject the null hypothesis of underidentified instruments for all 2SLS regressions. The p-value of Hansen J statistics suggests that we cannot reject the null hypothesis that the instrumental variables are exogenous except  $W^{distance}$ , which means IV instruments we choose in this paper are sufficient.

As shown in Table 4, Column 1–6 presents results with  $W^{border}$ ,  $W^{distance}$ ,  $W^{eco}$ ,  $W^{eco*border}$ ,  $W^{region}$  and  $W^{region*eco}$ , respectively. Overall, under at least four types of spatial matrix except for  $W^{distance}$  and  $W^{eco*border}$ , we have proved that there's strategic interaction among jurisdictions in the process of environmental policymaking. However, no significant strategic interaction is found among geographically close provinces, which may be related to the extent of pollution spillover; because local governments are expected to make decisions independently when dealing with environmental issues that have local causes (Kostka and Nahm 2017). Provinces sharing the common border are inclined to imitate their neighbors' behavior, consistent with jurisdictions' behavior that belongs to the same region. One percent of local environmental regulation's increase will lead to a 0.329% and 0.459% increase of its neighbors. It's probably because these provinces are usually faced with a similar ruling environment; thus, it's possible to replicate neighbors' experiences at a low cost (Hong et al. 2019). Moreover, the magnitude is larger when provinces are within one region, suggesting the significance of closer regional ties in strategic policymaking.

Besides, the interactive pattern is dominated by strategic substitution among provinces with similar economic levels. That is, when neighbors implement

stricter (laxer) environmental policies, local governments will respond with laxer (stricter) guidelines, which is consistent with conclusions drawn by Vrijburg and Mooij (2016), Chirinko and Wilson (2017) and Parchet (2019). Specifically, compared with those pure economic proximity provinces ( $\rho = -0.114$ ), the magnitude of the reaction coefficient is slightly larger when economically similar provinces belonging to the same region ( $\rho = -0.142$ ). As mentioned above, the growth-oriented political incentives make local officials put economic performance before environmental protection. Economically similar provinces are regarded as the primary competitors for attracting capital and winning political promotion. Thus, they are more likely to strategically make environmental decisions (Yu et al. 2016; Zhang et al. 2020b, 2021).

Regarding the control variables, economic development and its quadratic term are significantly positive in all kinds of spatial weight matrices, indicating a U-shape relationship between economic development and environmental regulation. i.e., with the improvement of economic development, environmental regulation intensity first decreases. When the economic development reaches and exceeds a certain degree, environmental regulation intensity starts to increase (Pan et al. 2020), consistent with the logic of EKC hypothesis. Meanwhile, industry and energy structure positively affect environmental regulation, suggesting the mitigation effects of cleaner production technologies on emissions. The coefficient of fiscal decentralization is significantly positive, implying that localities adjust their behavior with improved regulations to satisfy the requirements from the top (van Rooij et al. 2017; Chen et al. 2018). Nevertheless, the structure of ownership has a negative effect on environmental regulation, which implies that provinces with a higher proportion of state-owned enterprises are more inclined to relax environmental control.

#### Asymmetric effects of strategic interaction

Moreover, provinces may not react uniformly to the environmental policy change of competitors. Instead, they may respond only when competitors' behavior puts them at a disadvantage to attract economic investment. Table 5 reveals local governments' response when competitors' environmental regulation



**Table 4** Interactive patterns of environmental regulation competition

DV = lnERS	Geographical proximity matrix		Economic proximity matrix		Regional proximity matrix	
	$W^{border}$	$W^{distance}$	$W^{eco}$	$W^{eco*border}$	$W^{region}$	$W^{region*eco}$
$\rho$	0.329* (0.186)	- 0.364 (0.415)	- 0.114*** (0.044)	0.183** (0.079)	0.459** (0.200)	- 0.142*** (0.049)
lpgdp	0.642*** (0.183)	0.563*** (0.198)	0.612*** (0.195)	0.502*** (0.179)	0.550*** (0.186)	0.621*** (0.194)
lpgdp2	0.119*** (0.031)	0.108*** (0.032)	0.106*** (0.030)	0.123*** (0.031)	0.141*** (0.033)	0.104*** (0.031)
lpop	- 0.305 (0.433)	- 0.468 (0.414)	- 0.404 (0.409)	- 0.513 (0.397)	- 0.394 (0.421)	- 0.473 (0.408)
itech	0.371 (0.257)	0.260 (0.271)	0.182 (0.260)	0.367 (0.270)	0.226 (0.272)	0.225 (0.265)
public	- 0.005 (0.096)	0.051 (0.086)	0.040 (0.095)	0.050 (0.090)	0.002 (0.090)	0.045 (0.090)
industry	0.972*** (0.212)	0.929*** (0.217)	1.015*** (0.227)	0.862*** (0.208)	0.846*** (0.230)	1.117*** (0.240)
fdi	0.096 (0.771)	0.518 (0.699)	0.673 (0.698)	0.009 (0.711)	- 0.098 (0.804)	0.761 (0.730)
energy	0.189** (0.083)	0.148* (0.083)	0.180** (0.081)	0.102 (0.088)	0.191** (0.086)	0.145* (0.080)
budget	0.024** (0.010)	0.022** (0.011)	0.021* (0.011)	0.034*** (0.012)	0.018 (0.012)	0.021* (0.011)
nation	- 1.515** (0.600)	- 1.065* (0.604)	- 1.058* (0.576)	- 1.250** (0.590)	- 1.429** (0.636)	- 1.109* (0.582)
constant	2.403 (3.327)	5.401 (3.373)	4.277 (2.843)	4.259 (2.793)	2.776 (3.109)	4.852* (2.836)
No. of Obs	360	360	360	360	360	360
Hausman test Prob > chi2	0.000	0.000	0.000	0.000	0.000	0.000
FE/RE	FE	FE	FE	FE	FE	FE
Kleibergen–Paap rk LM	66.524	21.892	73.210	65.088	95.724	40.546
( <i>p</i> value)	(0.000)	(0.009)	(0.000)	(0.000)	(0.000)	(0.000)
Hansen J	7.239	15.683	11.912	18.556	5.125	11.757
( <i>p</i> value)	(0.511)	(0.047)	(0.155)	(0.017)	(0.744)	(0.162)
R-squared	0.421	0.413	0.408	0.414	0.381	0.406

Heteroscedastic robust standard error in parentheses. \*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively. Both space and time effects are fixed

is stricter or more relaxed than last year. Results show that asymmetric response only occurs in regions with similar economic levels, which aligns with the capital competition hypothesis. Local officials are more sensitive to their neighbor’s policymaking change, especially the economically similar provinces which are being treated the primary rivals in competition for

scarce capital and political opportunities (Yu et al. 2016; Zhang et al. 2020b). Notably, no matter how the direction of neighbors’ policy change compared with that in last year, localities will adjust in the opposite accordingly. That may be related to regional economic heterogeneity; even though provinces are economically similar, they may also be diverse in other aspects,

**Table 5** Asymmetric effects of strategic interaction in Eq. (2)

DV = lnERS	Geographical proximity matrix		Economic proximity matrix		Regional proximity matrix	
	$W^{border}$	$W^{distance}$	$W^{eco}$	$W^{eco*border}$	$W^{region}$	$W^{region*eco}$
Competitors' environmental regulation More Relaxed Than Last Year ( $\lambda_1$ )	0.173 (0.210)	– 0.438 (0.548)	– 0.271** (0.111)	– 0.010 (0.131)	0.288 (0.207)	– 0.193*** (0.062)
Competitors' environmental regulation Stricter Than Last Year ( $\lambda_2$ )	0.242 (0.201)	– 0.386 (0.537)	– 0.224*** (0.084)	– 0.138 (0.107)	0.302 (0.205)	– 0.169*** (0.055)
Control variables	YES	YES	YES	YES	YES	YES
No. of Obs	330	330	330	330	330	330
Hausman test Prob > $\chi^2$	0.000	0.000	0.000	0.131	0.000	0.159
FE/RE	FE	FE	FE	RE	FE	RE
Kleibergen–Paap rk LM ( <i>p</i> value)	15.145 (0.056)	33.361 (0.000)	17.102 (0.029)	7.485 (0.485)	69.168 (0.000)	27.184 (0.001)
Hansen J ( <i>p</i> value)	10.812 (0.147)	13.166 (0.068)	8.360 (0.302)	2.944 (0.890)	2.902 (0.894)	9.395 (0.226)
R-squared	0.536	0.422	0.259	0.457	0.483	0.241

Heteroscedastic robust standard error in parentheses. \*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively

such as economic scale and industrial structure, leading to various responsive outcomes. For instance, those developed provinces may be devoted to attracting nonpolluting industries, highlighting their clean environment as a competitive advantage over their rivals instead of laxer environmental controls. By contrast, those areas preferring pollution-intensive industries will apply laxer environmental policies to respond to neighbors' stricter environmental regulations (Konisky 2007; van Rooij et al. 2017).

Meanwhile, Table 6 shows local governments' response when competitors' environmental regulation is more relaxed or stricter than itself. To be specific, only  $W^{border}$  and  $W^{eco*border}$  in columns 1 and 4 have passed relevant tests; thus, we mainly focus on these results.  $\lambda_1$  and  $\lambda_2$  are both significantly positive, implying the existence of both race to the bottom and race to the top effect, suggesting the complexity of strategic interaction among local governments (Konisky 2007). Provinces that share the common border are usually with a similar social and cultural environment. Hence, they are more likely to imitate neighbors' behaviors and replicate their experiences. Nevertheless, the magnitude of environmental regulation is much larger when competitors' environmental regulation is more relaxed, which means that local

governments are more sensitive to neighbors' laxer policy, indicating a more significant trend of racing to the bottom. In sum, interaction among provinces, especially the tendency to race to the bottom, may weaken the emission reduction effect of environmental regulation, causing severe environmental pollution. However, empirical evidence in this regard is scarce. Thus, in the next section, we will incorporate the local and its competitors' environmental regulation into the same model to further investigate the environmental impact of environmental regulation competition.

#### Effect of environmental regulation competition on environmental pollution

The spatial econometric method is applied to investigate the effect of environmental regulation competition on environmental pollution. Several spatial model diagnosis tests should be performed before conducting the estimation results (Table 7). Firstly, the LM test and Robust LM test are conducted to confirm spatial econometric models' necessity. Under the spatial matrix of  $W^{border}$ , most reject the null hypothesis that there is no spatial lag and spatial error autocorrelation, which suggests that the spatial panel model is better than the traditional panel model

**Table 6** Asymmetric effects of strategic interaction in Eq. (3)

DV = lnERS	Geographical proximity matrix		Economic proximity matrix		Regional proximity matrix	
	$W^{border}$	$W^{distance}$	$W^{eco}$	$W^{eco*border}$	$W^{region}$	$W^{region*eco}$
Competitors' environmental regulation More Relaxed ( $\lambda_1$ )	0.519** (0.249)	0.188 (0.569)	- 0.127 (0.123)	0.466*** (0.139)	0.348 (0.350)	- 0.238* (0.134)
Competitors' environmental regulation Stricter ( $\lambda_2$ )	0.434** (0.207)	0.085 (0.536)	- 0.142** (0.071)	0.345*** (0.103)	0.371 (0.312)	- 0.176** (0.078)
Control variables	YES	YES	YES	YES	YES	YES
No. of Obs	360	360	360	360	360	360
Hausman test Prob > $\chi^2$	0.000	0.003	0.975	0.000	0.012	0.003
FE/RE	FE	FE	RE	FE	FE	FE
Kleibergen–Paap rk LM ( <i>p</i> value)	19.594 (0.012)	14.538 (0.069)	9.107 (0.333)	22.340 (0.004)	11.848 (0.158)	10.854 (0.210)
Hansen J ( <i>p</i> value)	7.811 (0.350)	14.409 (0.044)	10.903 (0.143)	11.122 (0.133)	4.368 (0.737)	9.669 (0.208)
R-squared	0.645	0.647	0.646	0.649	0.649	0.650

Heteroscedastic robust standard error in parentheses. \*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively

without a spatial effect. Secondly, the joint significance test of spatial fixed effects is used to confirm whether the spatial model can be expanded to both spatial fixed and time fixed model. Results show that the LR-test joint significance of spatial fixed and time fixed effects reject the null hypothesis at a 1% significance level, which implies that we should control both spatial fixed and time fixed effects. Thirdly, the selection of spatial econometric models. Wald test and LR test are employed to determine whether the spatial Durbin model can be simplified as a spatial error model or spatial lag model. Results show that we can reject the null hypothesis at a 1% significance level, indicating that the spatial Durbin model is more suitable than the spatial error model or spatial lag model (Elhorst and Freret 2009). Therefore, subsequent regression results are mainly based on spatial Durbin model.

Since the spillover effect of haze pollution is correlated with geographic proximity, thus in this section, we mainly apply two types of spatial matrix,  $W^{border}$ , and  $W^{distance}$ , respectively (Table 8). The coefficient of  $\rho$  is significantly positive, implying the existence of spillover effect of haze pollution, which has been proved in many literature pieces (Liu et al. 2017; Li et al. 2019b; Feng et al. 2020). A 1% increase

in local haze pollution will increase by 0.4% in its neighbors. Besides, the level of local haze pollution is also affected by its previous year, which captures the path dependence character (Li et al. 2019b). Moreover, the local environmental intensity has positively affected haze pollution, while only the regions sharing the common border have passed the significance test. At the same time, the increase in neighbors' environmental regulation intensity has alleviated the worsening of local haze pollution. When incorporated the local and neighbors' environmental regulation into one model, the coefficient's direction has not changed. Specifically, under the  $W^{border}$  spatial matrix, local policy implementation has significantly aggravated local haze pollution. However, under the  $W^{distance}$  spatial matrix, the neighbors' environmental policy has substantially alleviated local haze pollution. The results suggest that local haze pollution was jointly affected by local and neighbors' environmental regulation intensity; neglecting any of them will lead to biased estimation.

Possible explanations are as follows. Firstly, low environmental standards and weak enforcement have been widely blamed in China, causing the ineffectiveness of environmental policy (Wang and Wheeler 2005; Kostka 2014; van Rooij et al. 2017; Hao et al.

**Table 7** Spatial model diagnosis tests

	No fixed effects	Space-fixed effects	Time-fixed effects	Space–time fixed effects
LM Lag test	109.0596*** (0.000)	91.6315*** (0.000)	52.4195*** (0.000)	6.1682*** (0.013)
Robust LM Lag test	35.2853*** (0.000)	22.3900*** (0.000)	32.6745*** (0.000)	0.4020 (0.526)
LM Error test	75.3027*** (0.000)	71.4673*** (0.000)	25.3895*** (0.000)	5.7865*** (0.016)
Robust LM Error test	1.5283 (0.216)	2.2258 (0.136)	5.6445*** (0.018)	0.0203 (0.887)
Wald Spatial Lag	95.8574*** (0.000)	70.6806*** (0.000)	165.8125*** (0.000)	92.3434*** (0.000)
LR Spatial Lag	94.1789*** (0.000)	68.4189*** (0.000)	140.7835*** (0.000)	80.8836*** (0.000)
Wald Spatial Error	120.5643*** (0.000)	65.1488*** (0.000)	195.4481*** (0.000)	92.0675*** (0.000)
LR Spatial Error	271.9318*** (0.000)	64.5619*** (0.000)	159.1774*** (0.000)	79.6984*** (0.000)

*p* values are in parentheses. \*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively

2018b). When the local governments enhance environmental control, the polluting enterprises may have a trade-off between paying the charges and reducing emissions. If the former is profitable, enterprises will comply with policy instead of reducing emissions, thus causing more severe pollutions. Secondly, due to the spillover effect, the improvement of neighbors' air quality will benefit the local environment. However, in the long run, this may lead to a “free-ride” effect that each province will rely on their neighbors to strengthen environmental control rather than increasing their governance efforts. Consequently, the mitigation effect benefits from the adjacent areas are temporary, not the sustainable solution for haze governance. To sum up, after controlling for the spillover effect and hysteresis effect, the strategic interaction of environmental regulation among regions is not conducive to improving haze pollution.

Regarding the control variables, the U-shape relationship is found between economic and haze pollution in most models. The coefficient of FDI is significantly positive under  $W^{distance}$  spatial matrix, indicating that the introduction of FDI will harm local air quality, which, to some extent, confirms the pollution haven hypothesis in China. The coal-based

energy structure has aggravated haze pollution in China, suggesting the urgency to transform into the application to clean energy. As we have expected, the rapid growth of civil cars has brought significant challenges to air quality improvement.

## Conclusions and policy implications

Severe haze pollution has drawn growing public awareness in China. Central governments have conducted unprecedented environmental policies to mitigate air pollution; however, the expected goal has not been achieved yet. Poor regulatory enforcement and low environmental standard incurred by environmental regulation competition among local officials may cause this consequence. Thus, it is essential for environmental improvement to accurately identify the interactive patterns and characteristics of environmental regulation competition. Using panel data of 30 provinces in China from 2004 to 2015, this study applies a spatial econometric method to investigate environmental regulation competition patterns and their environmental impact. The conclusions are summarized as follows.

**Table 8** The effect of environmental regulation competition on haze pollution

DV = lnHP	Spatial matrix = $W^{border}$			Spatial matrix = $W^{distance}$		
$\rho$	0.409*** (0.054)	0.416*** (0.055)	0.416*** (0.054)	0.433*** (0.120)	0.464*** (0.118)	0.466*** (0.118)
lnHPt-1	0.322*** (0.045)	0.328*** (0.046)	0.327*** (0.045)	0.355*** (0.048)	0.436*** (0.051)	0.438*** (0.051)
lnERS	0.043* (0.024)		0.052** (0.025)	0.033 (0.024)		0.023 (0.024)
$W \times \lnERS$		- 0.030 (0.049)	- 0.062 (0.051)		- 0.430*** (0.108)	- 0.419*** (0.108)
lpgdp	- 0.144 (0.096)	- 0.146 (0.097)	- 0.141 (0.096)	- 0.178* (0.094)	- 0.182** (0.092)	- 0.193** (0.092)
lpgdp2	0.017 (0.015)	0.025* (0.014)	0.015 (0.015)	0.029** (0.013)	0.030** (0.013)	0.027** (0.013)
lpop	- 0.100 (0.166)	- 0.127 (0.166)	- 0.083 (0.167)	- 0.060 (0.133)	0.003 (0.132)	0.012 (0.132)
ltech	0.012 (0.103)	0.034 (0.103)	0.005 (0.103)	- 0.089 (0.096)	- 0.061 (0.094)	- 0.073 (0.094)
industry	0.118 (0.103)	0.171* (0.100)	0.114 (0.103)	- 0.001 (0.104)	0.098 (0.101)	0.070 (0.105)
fdi	0.446 (0.357)	0.481 (0.359)	0.451 (0.357)	0.670* (0.347)	0.791** (0.343)	0.770** (0.343)
energy	0.150*** (0.037)	0.156*** (0.037)	0.144*** (0.037)	0.149*** (0.037)	0.145*** (0.036)	0.144*** (0.036)
budget	- 0.004 (0.004)	- 0.003 (0.004)	- 0.004 (0.004)	- 0.006 (0.004)	- 0.007* (0.004)	- 0.008* (0.004)
public	- 0.019 (0.043)	- 0.017 (0.044)	- 0.017 (0.043)	- 0.008 (0.043)	- 0.008 (0.042)	- 0.009 (0.042)
nation	- 0.232 (0.214)	- 0.272 (0.215)	- 0.181 (0.218)	- 0.106 (0.208)	- 0.031 (0.206)	- 0.015 (0.207)
lcar	0.257** (0.107)	0.263** (0.108)	0.232** (0.109)	0.274*** (0.104)	0.272*** (0.103)	0.269*** (0.103)
rain	- 0.015 (0.026)	- 0.016 (0.027)	- 0.014 (0.026)	- 0.021 (0.026)	- 0.033 (0.026)	- 0.032 (0.026)
$W \times \text{lpgdp}$	- 0.154 (0.137)	- 0.095 (0.141)	- 0.114 (0.140)	- 0.148 (0.232)	0.212 (0.244)	0.193 (0.244)
$W \times \text{lpgdp2}$	- 0.060** (0.023)	- 0.062*** (0.024)	- 0.052** (0.024)	- 0.137* (0.074)	- 0.044 (0.077)	- 0.046 (0.077)
$W \times \text{lpop}$	0.426 (0.262)	0.396 (0.265)	0.382 (0.264)	0.864* (0.461)	0.259 (0.482)	0.251 (0.481)
$W \times \text{ltech}$	- 0.487*** (0.189)	- 0.489** (0.193)	- 0.431** (0.194)	- 1.506*** (0.499)	- 1.451*** (0.491)	- 1.416*** (0.491)
$W \times \text{industry}$	0.239 (0.173)	0.251 (0.179)	0.297* (0.179)	0.835* (0.453)	1.372*** (0.466)	1.337*** (0.466)
$W \times \text{fdi}$	- 0.374 (0.753)	- 0.205 (0.763)	- 0.253 (0.758)	2.292 (2.596)	6.814** (2.800)	6.632** (2.803)

**Table 8** continued

DV = lnHP	Spatial matrix = $W^{border}$			Spatial matrix = $W^{distance}$		
W × energy	0.111 (0.077)	0.096 (0.076)	0.123 (0.077)	0.512 (0.406)	0.573 (0.401)	0.595 (0.401)
W × budget	− 0.003 (0.007)	− 0.003 (0.007)	− 0.003 (0.007)	0.009 (0.017)	− 0.007 (0.017)	− 0.005 (0.017)
W × public	0.054 (0.088)	0.061 (0.088)	0.054 (0.088)	0.192 (0.228)	0.218 (0.223)	0.190 (0.225)
W × nation	− 0.738** (0.357)	− 0.675* (0.357)	− 0.774** (0.358)	0.108 (0.717)	0.306 (0.703)	0.220 (0.708)
W × lcar	0.029 (0.177)	− 0.044 (0.176)	0.015 (0.177)	− 0.143 (0.332)	− 0.509 (0.335)	− 0.465 (0.338)
W × rain	− 0.003 (0.041)	− 0.008 (0.041)	− 0.005 (0.041)	− 0.038 (0.123)	− 0.087 (0.119)	− 0.064 (0.122)
No. of Obs	330	330	330	330	330	330
Log_Like	575.24	573.61	575.76	583.49	587.46	587.87
R2_within	0.394	0.387	0.392	0.469	0.467	0.469

\*\*\*, \*\* and \* denotes significance at 1%, 5% and 10% level, respectively

Severe haze pollution has drawn growing public awareness in China. Central governments have conducted unprecedented environmental policies to mitigate air pollution; however, the expected goal has not been achieved yet. Poor regulatory enforcement and low environmental standard incurred by environmental regulation competition among local officials may cause this consequence. Thus, it is essential for environmental improvement to accurately identify the interactive patterns and characteristics of environmental regulation competition. Using panel data of 30 provinces in China from 2004 to 2015, this study applies a spatial econometric method to investigate environmental regulation competition patterns and their environmental impact. The conclusions are summarized as follows.

(1) Significant regional differences are observed in environmental regulation intensity. Eastern provinces have witnessed the strictest environmental policy, followed by the north-east, central, and western regions. Accordingly, haze pollution has expanded across most provinces, especially in the north of the Yangtze River. Moreover, significant spatial autocorrelation is found for environmental regulation and haze pollution and is dominated by high-high and

low-low cluster patterns. Even though the eastern provinces have relatively strict environmental control, some provinces like Shandong, Hebei, and Beijing still face severe haze pollution. This consequence may be associated with poor regulatory enforcement. However, less developed regions such as central and western regions are inclined to enforce a weaker environmental standard to maintain a competitive advantage. Therefore, central governments should tailor environmental policies based on regional conditions instead of a one-size-fits-all solution. For instance, eastern provinces need further strengthen environmental policy enforcement, whereas the central and western regions need appropriately raise environmental standards. Additionally, spatial autocorrelation for environmental regulation and haze pollution implies that regional cooperation is crucial to solving the air pollution problem.

(2) Empirical results reveal that there is strategic interaction of environmental regulation among provinces. However, interactive patterns vary with different competitors. More specifically, economically similar provinces are dominated by strategic substitution, while the provinces sharing a common border or belonging to the



same region are dominated by strategic complementation. Furthermore, both race to the bottom and race to the top effect are found in the asymmetric test, indicating the complexity of environmental regulation competition in China. Notably, the magnitude is much larger when competitors implement laxer policies, meaning a more significant race trend to the bottom. Overall, the results are consistent with the capital competition hypothesis, that is, local governments treat environmental regulations as instruments in competition for mobile resources. However, because of regional heterogeneity, diverse responsive outcomes have been discovered among provinces, of which economically similar provinces are more sensitive to their competitors' policy adjustment. Meanwhile, the race to the top effect suggests the effectiveness of the performance appraisal system by central governments (Zhang and Wu 2018; Chen et al. 2018). Therefore, it is essential to reinforce centralized environmental governance and supervision. For example, the central government should reform the merit-based promotion system centered on economic growth by incorporating environmental performance. Considering that economically similar provinces are more inclined to implement policies strategically, an environmental performance weighting system based on economic similarity should be established. Concretely, provinces with different economic similarities will be assigned different environmental performance weights. Meanwhile, the environmental performance will be closely linked to the cadre promotion. Those local officials who continue to outweigh economic interests but at the expense of the environment will be punished or demoted.

- (3) Finally, the dynamic fixed effect spatial Durbin model is employed to investigate the environmental impact of environmental regulation competition. Results indicate that after controlling for the spillover effect and hysteresis effect of haze pollution, the strategic interaction of environmental regulation among regions is not conducive to improving haze pollution. The consequence may be correlated with the low environmental standards, weak regulation

enforcement, and the “free-ride” motive in China. Thus, a joint effort with all provinces is needed to solve the haze pollution problem. Administrative jurisdiction-based governance mode is not suitable for environmental issues with a strong spillover effect. However, interest conflict resulting from regional heterogeneity has increased the difficulty of cooperation. Therefore, the central government's coordination is necessary, i.e., establishing a joint prevention and control committee and setting minimum environmental standards.

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