Window Dressing: Changes in Atmospheric Pollution at Boundaries in Response to Regional Environmental Policy in China*

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Abstract: In decentralized environmental governance, local governments are likely to adopt the "beggar-thy-neighbor" strategy to relax regulations at boundaries. This study investigates the impact of China's Joint Atmospheric Prevention and Control Policy (JAPCP) in "2+26" cities enforced by the central government on pollution at provincial boundaries. The theoretical model suggests that dual incentives for environmental protection and economic growth may prompt local governments to reduce boundary pollution within the JAPCP-covered area while relocating pollution to uncovered boundaries. Based on Shandong Province data using the difference-in-differences approach, our analysis reveals a 9.6% decline in the air quality at JAPCP-covered boundaries compared to non-boundary areas and a 5.3% increase at JAPCP-uncovered boundaries, which is associated with migration of key regulated industries. Through examining annual work reports, we provide evidence that local governments modify regulatory intensity at various boundaries. These findings indicate that, while regional environmental policies are intended to promote inter-jurisdictional cooperation, the local government responses lead to unintended costs.

JEL classification: D62, H77, Q53, Q58

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1. Introduction

In countries like China and the United States, the responsibility for environmental regulations is decentralized among local governments. Due to the pollution externalities, local governments are prone to transferring pollution to their neighbors in the absence of coordination, as indicated by elevated pollution levels at jurisdictional boundaries (Cai et al., 2016; Lipscomb and Mobarak, 2017; Sigman, 2005). Consequently, there is a growing emphasis on regional environmental policies that foster cooperation among local governments (Böhmelt and Vollenweider, 2015; Cheng et al., 2019; Melillo and Cowling, 2002; Park et al., 2006; Solomon et al., 2014).

This study provides evidence of the potential "window dressing" by local governments in response to regional environmental policies. Specifically, local governments may substantially decrease pollution transfer in regions where collaboration is emphasized while augmenting it in areas not subject to regional environmental policies. Although there is a considerable amount of literature demonstrating the effects of regional environmental policies in reducing pollution (Du et al., 2021; Hand et al., 2014; Lorenz et al., 2008; Song et al., 2020), the true effects might have been

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overestimated because they rarely account for local governments' strategic responses and the consequent negative effects in areas not covered by the policies.

This study attempts to fill this crucial gap by introducing evidence from China. China provides an ideal quasi-experiment on this topic. First, China suffers from severe atmospheric pollution, especially in the border zones between provinces. Second, its vast territory and massive population necessitate China to decentralize environmental governance. In China, local governments have sufficient institutional incentives to pursue two conflicting goals—economic growth and environmental protection, making them susceptible to engaging in strategic environmental behaviors. Third, the Joint Atmospheric Prevention and Control Policy (JAPCP) in Beijing, Tianjin, and 26 cities in Hebei, Henan, Shandong, and Shanxi Provinces (abbreviation "2+26" cities) implemented by China's Ministry of Environmental Protection in 2017 is a typical regional environmental policy, aiming to promote coordination among local governments.

We propose a theoretical model to elucidate how local governments' strategic behavior changes following the implementation of JAPCP. In our model, local governments influence pollution distribution by shaping the distribution of polluting enterprises. Motivated by economic and environmental objectives, they concentrate polluting enterprises along provincial boundaries before the policy, thereby transferring spillover pollution to neighboring regions. The JAPCP is considered as an environmental coalition of covered areas, in which the objective function of each member includes pollution that spreads to the jurisdictions of other members. Local governments perform "window dressing" behaviors in accordance with the policy. The policy reduces environmental free-riding through the transfer of pollution to neighbors at policy-covered boundaries, resulting in a decline in polluting enterprises. On the contrary, at policy-uncovered boundaries where environmental free-riding is allowed, the number of polluting enterprises and associated pollution boundary effects tend to increase substantially.

We empirically examine the hypotheses proposed by the theoretical model using a sample from Shandong Province. Initially, we investigate the changes in pollution boundary effects caused by the JAPCP. Compared to the non-boundary areas, the atmospheric quality at the JAPCP-covered provincial boundaries improves by approximately 9.6%. In comparison, the atmospheric quality at the JAPCP-uncovered provincial boundaries deteriorates by approximately 5.3%, with a higher deterioration observed in areas closer to the provincial boundary (reaching 8.2% in areas with a distance to the boundary of less than 10 km). Thus, these results indicate that while the JAPCP promotes collaborative pollution prevention by local governments in policy-covered areas, it also leads to the displacement of pollution sources which deteriorates the pollution in policy-uncovered boundary areas. Further examination confirms that our findings are not a product of a particular delimitation approach or the comparison bias brought by the fact that the policy is only implemented in some cities.

According to previous studies, local governments influence the location of polluting enterprises through differential environmental enforcement (Cai et al., 2016; Dean et al., 2009; Kahn, 2004; Kahn and Mansur, 2013). We further investigate the relocation of polluting enterprises in response to JAPCP to reveal the mechanism. An industry-specific relocation of pollution sources and changes in "beggar-thy-neighbor" behaviors have been found. Although the total number of industrial enterprises declined at the provincial boundaries covered and not covered by the JAPCP policy, the industrial structure in the JAPCP-uncovered provincial boundaries changes significantly. The number of enterprises in key regulated industries dramatically increases at JAPCP-uncovered provincial boundaries, raising the share of heavily polluting industries. These results imply the existence of industry-specific strategic behaviors by the local governments. We also use the frequency of keywords related to environmental protection in government work reports to examine the change in environmental regulation intensities, which discloses that the local governments reduce the regulation intensities at the policy-uncovered boundaries after JAPCP.

Our empirical results demonstrate the negative aspects of regional environmental policies. As these policies apply only to some parts of the jurisdiction, local governments may strategically exert efforts in areas where policies are implemented while shirking in others, thus distorting the initial policy intention design by the central government. If the central government does not anticipate or account for these strategic responses, the regional environmental policies may inadvertently encourage spatial opportunism in pollution emission, thereby undermining the overall effectiveness of the policy.

This study speaks to and extends three strands of the literature. First, we shed light on the potential plight of regional environmental policies by analyzing the strategic behavior of local governments. Although extensive literature evaluates various regional environmental policies, such as the Regional Haze Rule in America (Hand et al., 2014), the Convention on Long-Range Transboundary Air Pollution (CLRTAP) in Europe (Byrne, 2017; Lorenz et al., 2008), and Joint Atmospheric Prevention and Control Policy (JAPCP) of different periods in China (Du et al., 2021; Wang et al., 2016; Wang et al., 2014; Wu et al., 2015), most of them focus on the overall policy effects on where these policies are implemented. Previous literature ignores the spatial effects of regional policy and the underlying mechanisms. While Song et al. (2020) also employ the JAPCP in "2+26" cities in 2017, our study goes beyond by demonstrating the spatial responses of local governments to JAPCP and the changes in pollution boundary effects, indicating the incomprehensiveness of Song et al.'s (2020) estimation. This study also provides theoretical explanations and empirical evidence of the strategic behaviors of local governments in response to regional environmental policies.

Second, this study enriches the literature on pollution boundary effects. A large number of empirical studies have identified the existence of pollution boundary effects and analyzed the political and economic factors behind the phenomenon (Bernauer and Kuhn, 2010; Cai et al., 2016; Duvivier and Xiong, 2013; Gray and Shadbegian, 2004; Helland and Whitford, 2003; Kahn, 2004; Lipscomb and Mobarak, 2017; Sigman, 2005), but the following aspects are ignored by these studies. Most importantly, these studies focus more on national boundaries than on subnational administrative boundaries within a country. Furthermore, the boundary effects of river pollution have been discussed more than those of atmospheric pollution. As the riverways and flow directions are determined, the diffusion direction of river pollutants is unidirectional. However, the direction of atmospheric pollutant diffusion is uncertain, making it more challenging to identify the boundary effect of atmospheric pollution than that of river pollution. Finally, nearly all relevant studies have focused on the existence of pollution boundaries and the measurement of boundary effects. To the best of our knowledge, no study has examined the dynamic changes in pollution boundary effects caused by policies.

Third, this study enriches the discourse on environmental decentralization. Environmental federalism argues that efficient environmental regulation relies on decentralization among the different levels of government (Oates and Portney, 2003; Veld and Shogren, 2012). However, due to pollution externalities and other incentives for local governments, a growing number of studies have found that excessive decentralization may have less conducive effects on environmental governance (Fell and Kaffine, 2014; Kahn et al., 2015; Lovo, 2018; Sigman, 2014; Stewart, 1977). Oates and Portney (2003) point out that the trade-off between decentralization and centralization depends on the magnitude of welfare gains and environmental distortions from decentralization. Until now, the determination of the optimal decentralization structure has remained in the air. This study further reveals the potential limitations of environmental decentralization and the underlying political-economic reasons. Similar to previous studies (Cai et al., 2016; He et al., 2020), this study highlights an important principle in determining the decentralization structure by considering the strategic responses of local governments that collide with the central government's policy intentions.

The remainder of this paper is organized as follows. Section 2 provides the institutional background for this study. Section 3 develops a theoretical model for our propositions. Section 4 introduces the data and provides some characteristic facts about the pollution boundary effects in China. Section 5 estimates the change in pollution boundary effects at both boundaries and Section 6 delves into the examination of the underlying mechanisms driving such changes. Section 7 concludes the study.

2. Institutional background

2.1. Atmospheric pollution in China

Since the Reform and Opening-up in 1978, China has experienced unprecedented economic and social development, largely driven by massive consumption of fossil fuels (Kan et al., 2012). Within a few decades, China has encountered the environmental pollution problems that developed economies have grappled with throughout their industrialization course, with atmospheric pollution being particularly prominent. According to Rohde and Muller (2015), from April 5 to August 5, 2014, 92% of China's population experienced unhealthy air for at least 120 hours, and 38% experienced average concentrations that were unhealthy (US EPA standard). Although atmospheric pollutants significantly decreased from 2014 to 2018 (Fan et al., 2020), China still faces increasingly complex challenges in terms of atmospheric pollution (Zeng et al., 2019). For instance, the emission of CO_2 in China accounts for 30% of total global emissions in 2019, making it the largest emitter of CO_2 worldwide (Olivier and Peters, 2020).

In addition, China has to address the transboundary transfer of atmospheric pollutants, especially in the Beijing—Tianjin—Hebei Region (Huang et al., 2018; Wang et al., 2014). Zhu et al. (2011) find that the contribution of PM_{10} from long transport accounted for approximately 26% of the PM_{10} concentrations in urban Beijing.

Industrial enterprises are the main sources of atmospheric pollution in China (Zheng et al., 2016). According to the Second Census of Polluting Sources in 2017, industrial emissions account for 75.98%, 36.18%, and 75.44% of the total emissions of SO_2, NO_x, and particulate matter, respectively. The census reports indicate that atmospheric pollutants are primarily attributed to a few heavy-polluting industries.[1]

Poor atmospheric quality poses extreme socioeconomic costs in different aspects, such as residents' health (Ebenstein et al., 2017; He et al., 2016; Song et al., 2019), human capital (Xue et al., 2021), and subjective well-being (Chang et al., 2019; Zhang et al., 2017), among others. For

[1] Details can be found at https://www.mee.gov.cn/xxgk2018/xxgk/xxgk01/202006/t20200610_783547.html.

example, He et al. (2016) find that atmospheric pollution significantly affects mortality. More than 285,000 premature deaths in China could be averted each year if the current level of PM_{10} concentration were decreased by 10 μg/m^3. According to Xia et al. (2016), even considering only the reduced work time due to mortality, hospital admissions, and outpatient visits due to diseases resulting from atmospheric pollution, the total economic losses in 2007 reach 1.1% of China's GDP.

2.2. Environmental regulatory structure

Local officials in China frequently pursue their own interests in local environmental affairs, which is inextricably tied to China's environmental regulatory structure. The Ministry of Ecology and Environment (MEE) has centralized authority over the regulation of atmospheric pollution in China.[2] The MEE is responsible for developing and implementing nationwide environmental regulations and policies, as well as overseeing local environmental affairs. The local Department of Ecology and Environment (DEE), which is an essential division of the local government, actively engages in local pollution monitoring and law enforcement. As local governments dominate DEEs' staffing and funding, DEEs are subject to dual oversight from both the MEE and local governments.

Despite the dual oversight, information asymmetries and high monitoring costs between central and local governments have historically made DEEs more inclined to be receptive to their respective local governments (Zhou et al., 2013). Since the personnel appointment authority reform in 2016, provincial DEEs have assumed the responsibility of designating directors for municipal DEEs, taking over this authority from municipal governments (Kong and Liu, 2024). Nevertheless, provincial governments retain the right to designate directors for DEEs at the provincial level, enhancing their control over environmental affairs throughout the province. Consequently, provincial government has the ability to persuade DEEs to overlook specific environmental violations in service of local interests (Cao et al., 2019; Zhang, 2012). The central environmental authorities are typically only able to identify and address serious pollution incidents resulting from insufficient supervision after the fact (Cai et al., 2016).

2.3. Local governments' dual incentives

As local governments control DEEs, the incentives they face are essential for analyzing their behavior regarding environmental issues. In China, a principal-agent relationship exists between the central and local governments. The central government utilizes institutional incentives to motivate local governments toward achieving its goals. Thus, the central government maintains effective governance over a vast territory with a large population (Zhou, 2016).

It is important to note that local governments face multiple incentives, including the dual incentives of economic growth and environmental protection. Since the Reform and Opening-up, China's local governments have demonstrated a keen interest in economic growth, which is considered an important engine of China's economic development. Several studies have examined the sources of this incentive from different perspectives (e.g., Li and Zhou, 2005; Montinola et al., 1995; Qian and Weingast, 1997). Given the emphasis placed on economic growth over other socioeconomic goals, local governments acquiesce in the illegal production of polluting enterprises

[2] In March 2018, the newly formed Ministry of Ecology and Environment (MEE) takes over the administrative power of the former Ministry of Environmental Protection (MEP). MEE has also taken over the duty for the environmental regulation of ground water from the Ministry of Land and Resources (MLR).

for economic gain (Zhang, 2012).

The unilateral pursuit of economic growth by local governments without considering environmental pollution has drawn the attention of the central government (Zheng et al., 2014). With the release of the Tenth Five-Year Plan in 2001, pollution reduction became a national strategic goal for the first time. Since 2005, China's central government has shifted its national priority from development to "scientific development" and has introduced new criteria for assessing the performance of local governments. Under these criteria, pollution emission reduction plays a more important role in evaluation (Wang and Lei, 2020), which incentivizes local governments to protect the environment. Economic growth remains a vital performance indicator for local governments, creating a dilemma between environmental protection and economic growth (e.g., Zheng et al., 2014; Pu and Fu, 2018; Wang and Lei, 2020).

2.4. Pollution boundary effects in China

When there is insufficient coordination among local environmental agencies, relocating pollution enterprises to boundaries enables local governments to address the trade-off between economic growth and environmental protection. Polluting enterprises, although being the leading source of pollution, drive economic growth and provide considerable tax revenue for local governments. Polluting enterprises positioned close to boundaries, as opposed to those located in the center areas, can spread a substantial percentage of pollutants to neighboring areas. As polluting enterprises agglomerate at the boundaries, the pollution boundary effects are generated.

Polluting boundary effects are not unique to China, but they are more prominent in China under the Chinese-style decentralization and dual incentives, especially from 2001 to 2010 when the central government relies on target-based incentives to motivate local governments but faces challenges in effectively monitoring environmental enforcement (He et al., 2020). In 2001, the Tenth Five-Year Plan sets goals for pollution reduction. However, it lacks tangible measures of trans-provincial coordination. According to Cai et al. (2016), there is an increase in polluting activities in a province's downstream boundary counties during this period, which suggests that the local governments intend to transfer water pollution to neighboring provinces that are downstream. Ultimately, the lack of cooperation between local governments has hindered the achievement of national pollution reduction goals. In the subsequent period of the Eleventh Five-Year Plan period (2006–2010), the central government sets provincial pollution reduction goals but still fails to efficiently address the critical coordination issues. Although the pollution reduction goal of the Eleventh Five-Year Plan is eventually achieved by the end of 2010, the worsening trend of the environment has not been fully reversed (Zhang, 2012). Significantly, varying environmental regulation intensity imposed by the central government across regions during this period has prompted the spatial relocation of pollution-intensive activities and polluting enterprises. Consequently, this shift has exacerbated water pollution in upstream cities with less rigorous environmental regulations (Chen et al., 2018).

2.5. Joint atmospheric prevention and control policy in the "2+26" cities

Eliminating conflicts of interest between the central and local governments is critical for achieving the central government's environmental goals. Therefore, it is a common practice worldwide to seek a balance between decentralization and centralization regarding environmental issues (Chen et al., 2022). For instance, in the context of the European Commission's environmental coordinate framework, occurrences of international free-riding behavior among EU countries are insignificant (Sigman, 2002). The JAPCP is an attempt by China's central government to achieve this balance. By directly granting local governments pollution reduction mandates and requiring local governments to break down cooperative barriers, the JAPCP allows the central government to monitor local environmental affairs more closely.

The JAPCP in the "2+26" cities has two essential time points. The first is the release of the "2017 Atmospheric Pollution Prevention and Control Work Plan for Beijing-Tianjin-Hebei and Surrounding Areas" by the MEE on February 17, 2017, which initiated the JAPCP in the "2+26" cities.[3] The second is the release of the "2017–2018 Autumn and Winter Atmospheric Pollution Comprehensive Management Work Plan for Beijing-Tianjin-Hebei and Surrounding Areas" by the MEE in October 2017. This plan sets environmental objectives for the autumn and winter months and assigns tasks to the "2+26" cities.

The JAPCP in the "2+26" cities has four key features. First, the JAPCP is mandated by China's central government, precluding local governments from negotiating their inclusion within the "2+26" designation and thus positioning the policy as an exogenous shock for local governments. Second, the central government establishes inter-departmental and cross-provincial environmental protection institutions to promote cooperation among local governments. Third, the JAPCP emphasizes the principles of "unified planning, unified supervision, unified assessment, and unified coordination," reducing local government involvement in enforcing environmental regulations. Fourth, the JAPCP highlights the central government's supervision to reduce the spatial opportunistic behaviors of local governments.[4]

The implications of the JAPCP are twofold, as it has not resolved the conflicting incentives for economic growth and environmental protection. On the one hand, it promotes the collaborative efforts of local governments in pollution control. On the other hand, it motivates local governments to optimize the allocation of pollution reduction efforts. The JAPCP does not cover all areas of a particular province; therefore, local governments may engage in strategic "window dressing" behavior. Intuitively, the local government may strengthen pollution regulation within the JAPCP-covered area while relaxing it within the JAPCP-uncovered area (especially the boundary area not covered by JAPCP), leading to the transfer of polluting enterprises to the boundary areas not covered by JAPCP. Accordingly, this reduces the pollution reduction effect of the JAPCP.

3. Theoretical Model

In this section, we develop a model to analyze the strategic "window dressing" behavior of local governments following the implementation of the JAPCP.

3.1. Distribution of polluting enterprises before the JAPCP

We adopt the linear province specification following Dragone and Lambertini (2020). Suppose

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[3] Prior to 2017, China had a small-scale JAPCP in "2+4" cities (including Beijing, Tianjin, and four Hebei Province cities: Tangshan, Baoding, Langfang, and Cangzhou). In 2017, the coverage area of JAPCP was expanded to "2+26" cities. We list the "2+26" cities in Table A.3 of the Appendix. Notably, these cities are concentrated at the junction of four provinces.

[4] For example, after the first quarter of 2017, the MEE deployed thousands of environmental enforcement officers nationwide to conduct intensive inspections of JAPCP cities. Cities that failed to implement environmental regulations were criticized publicly, forcing local governments to efficiently engage in collaborative management.

an economy comprises three provinces as shown in Fig. 1. The ranges for Provinces A, B, and C are $(0, a)$, (a, b), and (b, c), respectively. Assume that the terrain is plain, that is, no geographical factors impede the spread of pollution, such as high mountains. The following analysis focuses on Province B. Polluting enterprises are substantial sources of atmospheric pollution, and local governments may manipulate the geographical distribution of polluting enterprises by influencing the enforcement of local environmental regulations (Cai et al., 2016; Dean et al., 2009). Therefore, we assumed that local governments influence pollutant distribution by influencing the distribution of polluting enterprises.

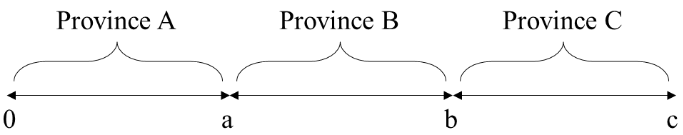

Fig. 1. Model set-up before the JAPCP.

Assuming that polluting enterprises are homogeneous, the total output produced by polluting enterprises located at $x\ (a < x < b)$ is $A_x I_x^\alpha$, where I_x denotes the number of polluting enterprises, $\alpha\ (0 < \alpha < 1)$ is used to portray diminishing marginal output, and A_x is a multiplier for differentiated regional productivity. Polluting enterprises at x generate $B_x I_x^\alpha$ unit of direct pollution on x and $B_y I_x^\alpha \delta^{|y-x|}$ unit of spillover pollution on $y \in (0, c)$. B_y (and B_x) reflects the heterogeneity of the vulnerability to pollution at different locations. The larger the B_y, the greater the amount of pollution it receives. The spillover of pollution decreases as region y moves further away from x, which is represented by the terms $\delta^{|y-x|}$. Therefore, the sum of direct pollution and spillover pollution imposed on Province B from polluting enterprises at x is

$$Pollution_B(I_x) = B_x I_x^\alpha + \int_a^b B_y I_x^\alpha \delta^{|y-x|} dy\,. \tag{1}$$

Suppose that the cost of establishing a polluting enterprise is $(1 + r)C$, where constant C denotes the constant marginal establishment cost, and r denotes the discount rate. Given that local governments have dual incentives of economic growth and environmental protection, we weight the economic output and pollution in local government policymaking as m and n, respectively.[5] If the government of Province B is rational, it seeks to maximize the following function by determining the number of polluting enterprises:[6]

$$\max_{I_x} W_B = \int_b^a \left[m A_x I_x^\alpha - n \left(B_x I_x^\alpha + \int_a^b B_y I_x^\alpha \delta^{|y-x|} dy \right) - (1 + r) C I_x \right] dx\,, \tag{2}$$

where I_x is a function of $x\ (a < x < b)$ which describes the distribution of polluting enterprises in Province B. Assuming constant marginal effects for economic output and pollution in the objective function, the integral sign in Equation (2) can be omitted, making the optimization problem equivalent to solving for the optimal number of enterprises for each region x individually.

5 This setting implies that the marginal effects of economic output and pollution in the local government objective function are constant. In the Appendix, we discuss a model of increasing marginal disutility of pollution. The extended model gives us similar theoretical propositions.

6 Local governments are concerned about the total pollution and economic output within their jurisdictions, but the objective function here only includes the pollution and output from polluting enterprises in Province B, omitting a term representing pollution spillovers from other provinces. This omission results from the constant marginal effects of pollution (n) in the objective function; hence, an equivalent approach would involve eliminating variables influenced by external agents from the objective function. In the extended model in the Appendix, where variable marginal effects are taken into account, the equilibrium arises as a result of a three-agent game.

The first-order condition allows us to achieve the optimal number of polluting enterprises in region x of Province B:

$$I_{B,x}^{*}=\left[\frac{\alpha\left(mA_x-nB_x-n\int_a^b B_y\delta^{|y-x|}dy\right)}{C(1+r)}\right]^{\frac{1}{1-\alpha}},x\in(a,b). \tag{3}$$

Evidently, $I_{B,x}^{*}$ increases as the numerator increases. For simplicity, we ignore the heterogeneity of productivity and pollution across regions by setting the parameters A_x and B_x to constants A and B, respectively. Therefore, $I_{B,x}^{*}$ decreases as the $\int_a^b B_y\delta^{|y-x|}dy$ increases. This term represents the spillover of pollution in Province B, led by the unit output at x. We denote this term as $SE_B(x)$, which can be rewritten as

$$SE_B(x)=\frac{B}{\ln\delta}(\delta^{x-a}+\delta^{b-x}-2). \tag{4}$$

The first-order and second-order derivatives of $SE_B(x)$ are

$$\frac{\partial SE_B(x)}{\partial x}=B(\delta^{x-a}-\delta^{b-x}), \tag{5}$$

$$\frac{\partial^2 SE_B(x)}{\partial x^2}=B\ln\delta\,(\delta^{x-a}+\delta^{b-x})<0. \tag{6}$$

According to Equation (6), $SE_B(x)$ achieves a maximum value at $x=(a+b)/2$, which enables $I_{B,x}^{*}$ to achieve a minimum value at $x=(a+b)/2$. This result indicates a concentration of polluting enterprises toward the provincial boundaries in Province B, whereas a comparatively lower density in the central region. An intuition explanation is that the pollution spillovers in the central region are largely absorbed by province B, whereas nearly half of the spillovers at boundaries are transferred to neighboring provinces. By strategically devoting more polluting companies to the boundaries, local governments achieve the optimum trade-off between environmental protection and economic growth.

By combining Equation (3) with the substitutions $A_x=A$ and $B_x=B$ and Equation (4), $I_{B,x}^{*}$ can be rewritten as

$$I_{B,x}^{*}=\left[\frac{\alpha\ln\delta\,(Am-Bn)-Bn\alpha(\delta^{x-a}+\delta^{b-x}-2)}{C(1+r)\ln\delta}\right]^{\frac{1}{1-\alpha}},x\in(a,b). \tag{7}$$

Similarly, we obtain $I_{A,x}^{*}$ and $I_{C,x}^{*}$ as follows:

$$I_{A,x}^{*}=\left[\frac{\alpha\ln\delta\,(Am-Bn)-Bn\alpha(\delta^{x}+\delta^{a-x}-2)}{C(1+r)\ln\delta}\right]^{\frac{1}{1-\alpha}},x\in(0,a), \tag{8}$$

$$I_{C,x}^{*}=\left[\frac{\alpha\ln\delta\,(Am-Bn)-Bn\alpha(\delta^{x-b}+\delta^{c-x}-2)}{C(1+r)\ln\delta}\right]^{\frac{1}{1-\alpha}},x\in(b,c). \tag{9}$$

Based on this logic, the distribution of polluting enterprises in Provinces A and C is the same as that in Province B. Therefore, we can conclude that there are fewer enterprises in the center and more at the boundaries.

3.2. Distribution of polluting enterprises after the JAPCP

Through mandatory collaboration among provinces, JAPCP internalizes pollution spillovers within the covered areas. To address this situation, we propose that Provinces B and C establish an environmental coalition in which pollution spillovers generated by B or C are integrated into their respective optimization problems (see Fig. 2). Hereafter, the boundary between Provinces B and C is termed the "policy-covered boundary," whereas the boundary between Provinces B and A is termed the "policy-uncovered boundary."

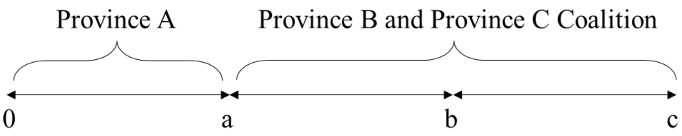

Fig. 2. Model set-up after the JAPCP.

Considering the pollution spillovers to Province C, the optimization problem for region $x \in (a, b)$ by the local government of Province B is:

$$\max_{I'_x} W'_B(I'_x) = mA_x {I'_x}^{\alpha} - n\left(B_x {I'_x}^{\alpha} + \int_a^b B_y {I'_x}^{\alpha} \delta^{|y-x|} dy + \int_b^c B_y {I'_x}^{\alpha} \delta^{|y-x|} dy\right) - (1+r)CI'_x. \quad (10)$$

Compared to Equation (2), the additional integrals from b to c reflect the inter-province pollution spillovers to Province C arising from polluting enterprises in region x. Assuming $A_x = A$ and $B_x = B$ as before, we can calculate the optimal number of polluting enterprises:

$$I^{*\prime}_{B,x} = \left[\frac{\alpha \ln \delta\,(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{c-x} - 2)}{C(1+r)\ln \delta}\right]^{\frac{1}{1-\alpha}}, x \in (a, b). \quad (11)$$

Considering the pollution spillovers into Province B, the optimization problem for Province C is formally identical to Equation (10). Thus, the optimal enterprise number $I^{*\prime}_{C,x}$ has the same form as $I^{*\prime}_{B,x}$, with the exception that the domain of definition becomes $x \in (b, c)$.

One can find that $I^{*\prime}_{B,x} < I^{*}_{B,x}$ and $I^{*\prime}_{C,x} < I^{*}_{C,x}$, indicating a decrease in polluting enterprises in Provinces B and C after policy implementation. Given that the policy has no effect on Province A, the distribution of polluting enterprises in Province A remains unchanged (i.e., $I^{*\prime}_{A,x} = I^{*}_{A,x}$).

3.3. Distribution of polluting enterprises

After discussing the optimal number of polluting enterprises, we focus on the distribution of pollution. Pollution at x comes from two sources: direct pollution from enterprises at x and the pollution spillovers from polluting enterprises in other regions.

Before the JAPCP, the pollution at x in Province B is

$$P_B(x) = B_x\left(I^{*}_{B,x}\right)^{\alpha} + \int_0^a B_x\left(I^{*}_{A,y}\right)^{\alpha}\delta^{|x-y|}dy + \int_a^b B_x\left(I^{*}_{B,y}\right)^{\alpha}\delta^{|x-y|}dy + \int_b^c B_x\left(I^{*}_{C,y}\right)^{\alpha}\delta^{|x-y|}dy. \quad (12)$$

The first term on the right-hand side of Equation (12) represents direct pollution, and the last three terms represent pollution spillovers from polluting enterprises in the three provinces. After the implementation of the JAPCP, pollution at x in Province B becomes

$$P'_B(x) = B_x\left(I^{*\prime}_{B,x}\right)^{\alpha} + \int_0^a B_x\left(I^{*\prime}_{A,y}\right)^{\alpha}\delta^{|x-y|}dy + \int_a^b B_x\left(I^{*\prime}_{B,y}\right)^{\alpha}\delta^{|x-y|}dy + \int_b^c B_x\left(I^{*\prime}_{C,y}\right)^{\alpha}\delta^{|x-y|}dy. \quad (13)$$

The above equation cannot be directly simplified; therefore, we present the results of the numerical simulation. Setting $a = 1$, $b = 2$, $c = 3$, $A = 2$, $B = C = 1$, $n = 1$, $\alpha = 0.1$, $\delta = 0.1$, and $r = 0.1$, Fig. 3 shows the distribution of polluting enterprises with different values of m.

As the preset parameter n is 1, the value of m represents the relative importance of economic growth versus environmental protection. Panel A in Fig. 3 illustrates that regardless of the value of m, the distribution of pollution in Province B shows a U-shaped curve. This implies that the pollution boundary effect is bound to exist if dual incentives exist. Increasing the relative importance of environmental protection (i.e., decreasing m) will result in a widening gap in pollution between the central areas and the boundary, which is consistent with the findings of Cai et al. (2016) based on China's Tenth Five-Year Plan (2001-2005). Based on the comparison of Panels A and B in Fig. 3, it is evident that JAPCP reduced pollution in Province B, especially in the vicinity of the policy-covered boundary.

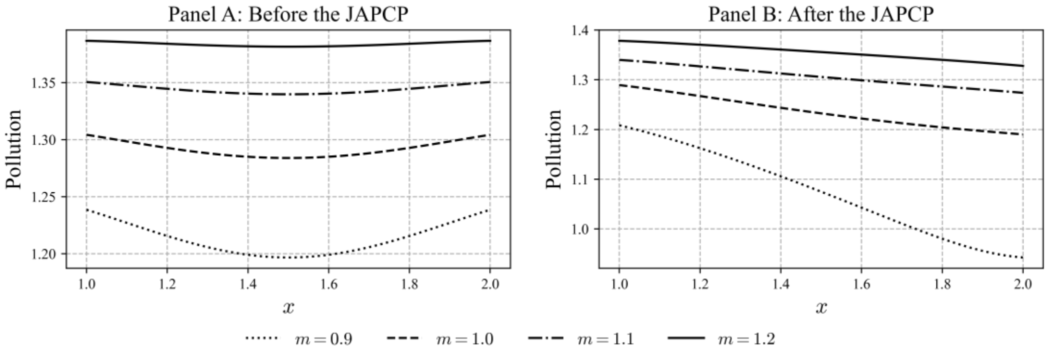

Fig. 3. Pollution distribution in Province B before and after the JAPCP.

3.4. Policy effects

Accounting for the varying policy effects in different regions, we define policy effects as the reduction in the proportion of pollution after the implementation of the policy, which can be written as

$$Policy\ Effects_x = \frac{P_B(x) - P_B'(x)}{P_B(x)}. \tag{14}$$

Fig. 4 shows the policy effects at different locations within Province B when m and δ are set to different values. The parameter δ measures the attenuation rate of pollution spillovers with distance. That is, given a constant distance, a smaller δ means weaker spillovers. As shown in Fig. 4, given a constant δ, the policy effects decrease with an increasing m. This finding indicates that the rising incentive for environmental protection motivates local governments to devote additional efforts to internalizing pollution externalities. Fig. 4 also shows that given a constant m, the policy effects increase with the increasing δ. As the attenuation rate of pollution spillovers decreases with larger δ, the aggregate pollution caused by pollution spillovers increases. Hence, a larger δ corresponds to more pronounced policy effects in terms of internalizing pollution externalities. Furthermore, regardless of the value of δ and m, a trend can be seen in Fig. 4 that policy effects gradually increase as locations approach the policy-covered boundary (i.e., $x = 2$) but gradually weaken as locations approach the policy-uncovered boundary (i.e., $x = 1$). Based on this scenario, pollution reduction at the policy-covered boundary is greater than that at the policy-uncovered boundary, resulting in opposite changes in the pollution boundary effects for the two boundaries.

Proposition 1. *The JAPCP leads to the decrease of pollution boundary effects at the policy-covered boundary but the increase of pollution boundary effects at the policy-uncovered boundary.*

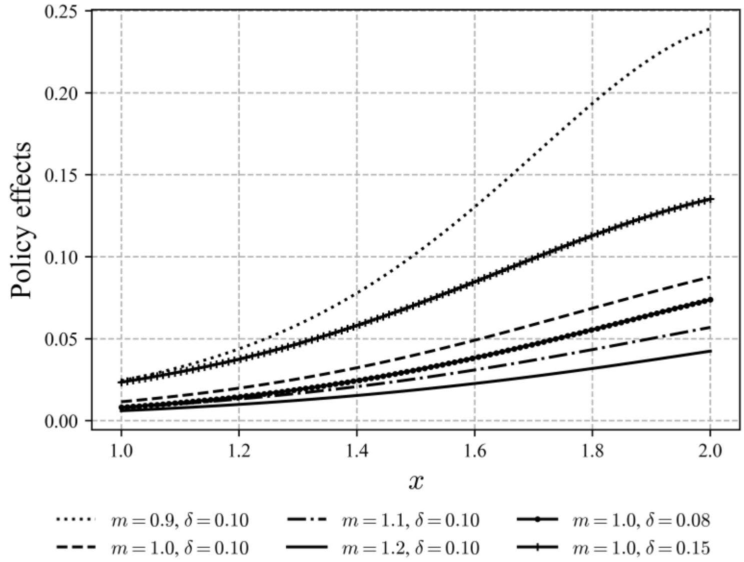

Fig. 4. Policy effects in different regions of province B.

The distribution of polluting enterprises determines the distribution of pollution; therefore, we investigate changes in the distribution of polluting enterprises. We denote ΔI_x as the change in the proportion of polluting enterprises, which can be expressed as

$$\Delta I_x = \frac{I^*_{B,x} - I^{*\prime}_{B,x}}{I^*_{B,x}} = 1 - \left[\frac{\alpha \ln \delta(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{c-x} - 2)}{\alpha \ln \delta(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{b-x} - 2)}\right]^{\frac{1}{1-\alpha}}. \quad (15)$$

The term that determines the monotonicity of Equation (15) is

$$f(x) = \frac{\alpha \ln \delta(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{c-x} - 2)}{\alpha \ln \delta(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{b-x} - 2)}, x \in (a, b), \quad (16)$$

and the first-order derivative of Equation (16) is given by

$$f'(x) = \frac{Bn\alpha^2 \ln \delta\,(\delta^{b-x} - \delta^{c-x})[2Bn(\delta^{x-a} - 1) - \ln \delta\,(Am - Bn)]}{[\alpha \ln \delta(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{b-x} - 2)]^2}. \quad (17)$$

We assume that $I^{*\prime}_{B,x}, I^{*\prime}_{C,x} > 0$, which means that polluting enterprises exist in any location, and the following inequality holds:

$$\alpha \ln \delta\,(Am - Bn) - Bn\alpha(\delta^{x-a} + \delta^{c-x} - 2) < 0. \quad (18)$$

As $x \in (a, b)$, we have $\delta^{x-a} > \delta^{c-x}$. Hence, we obtain the following inequality from Equation (18):

$$2Bn(\delta^{x-a} - 1) - \ln \delta\,(Am - Bn) > Bn(\delta^{x-a} + \delta^{c-x} - 2) - \ln \delta\,(Am - Bn) > 0. \quad (19)$$

It is easy to deduce that $Bn\alpha^2 \ln \delta\,(\delta^{b-x} - \delta^{c-x}) < 0$. Therefore, the numerator of Equation (17) is negative. This finding indicates that $f(x)$ monotonically decreases in (a, b), which in turn shows that ΔI_x monotonically increases in (a, b).

Proposition 2. *Pollution boundary effects are driven by changes in the distribution of polluting enterprises. The JAPCP leads to the concentration of polluting enterprises at policy-uncovered boundaries.*

4. Data

4.1. Data resources

The monthly atmospheric quality panel data gathered from the Chinese monitoring stations between January 2015 and December 2018 are employed in the empirical analysis.[7] These data consist of three main parts.

The first part comprises atmospheric quality data, including the Air Quality Index (AQI) and the concentrations of $PM_{2.5}$, PM_{10}, CO, and NO_2 at each atmospheric quality monitoring station. Since 2012, China's Ministry of Ecology and Environment has constructed a national monitoring network with 1,436 atmospheric quality monitoring stations in 338 cities and has published a new version of the real-time AQI. This study uses data from 595 monitoring stations in the Shandong, Shanxi, Henan, and Hebei Provinces. The raw data are recorded daily. We calculate each monitoring station's monthly average of AQI, $PM_{2.5}$, PM_{10}, CO, and NO_2. We have also obtained the coordinates of each monitoring station and calculated the least linear distance from each monitoring station to the provincial boundaries using ArcGIS 10.8.

The second part comprises weather data, including the temperature, wind speed, and wind direction in each city. Daily weather data are obtained from the website, http://www.tianqihoubao.com/, which records historical weather data in China. Then, we calculate the monthly average of daily maximum temperature, monthly average of daily minimum temperature, and monthly wind speed, and use the mode of the wind direction to represent the monthly wind direction.

The third part incorporates city-year-level data concerning polluting enterprises across various industries, frequencies of environmental protection-related keywords in government work reports, and specific socioeconomic indicators. The first two components aim to investigate the mechanisms driving changes in pollution boundary effects. Socioeconomic indicators, including city-level GDP and population, serve as pivotal control variables in the empirical analysis. The content of each government work report is individually downloaded from the respective official websites, and the frequencies of keywords are subsequently computed.[8] Other data are sourced from the statistical yearbooks of each city. In the following analysis, all city-level data are matched to station-level data according to the geographical location of each monitoring station.

4.2. Pollution boundary effects

Theoretically, pollution boundary effects are typically manifested as more pollution at the boundaries than at the centers due to the strategic behaviors of local governments. However, the pollutant distribution pattern does not apply to every province owing to several other influencing factors. Fig. 5 shows the relationship between the AQI and distance to the provincial boundaries in the four provinces from January 2015 to March 2017. According to this figure, only Shandong appears to have higher pollution levels at the provincial boundary. To enhance accuracy, we have regressed the AQI on the distance to the provincial boundary, as presented in Appendix Table A.1. We find that AQI and distance are negatively correlated at the 1% level in Shandong Province, which is in line with pollution boundary effects. However, such a relationship does not appear to exist in other provinces.

[7] The Ministry of Ecology and Environment (MEE) has directly established atmospheric quality monitoring stations throughout China, and local governments have almost no authority to alter station locations. Actually, the location of the monitoring stations remains remarkably constant.

[8] As an example, the government work report for Jinan in 2019, covering activities in 2018, is available at http://www.jinan.gov.cn/art/2019/3/4/art_114360_4942429.html.

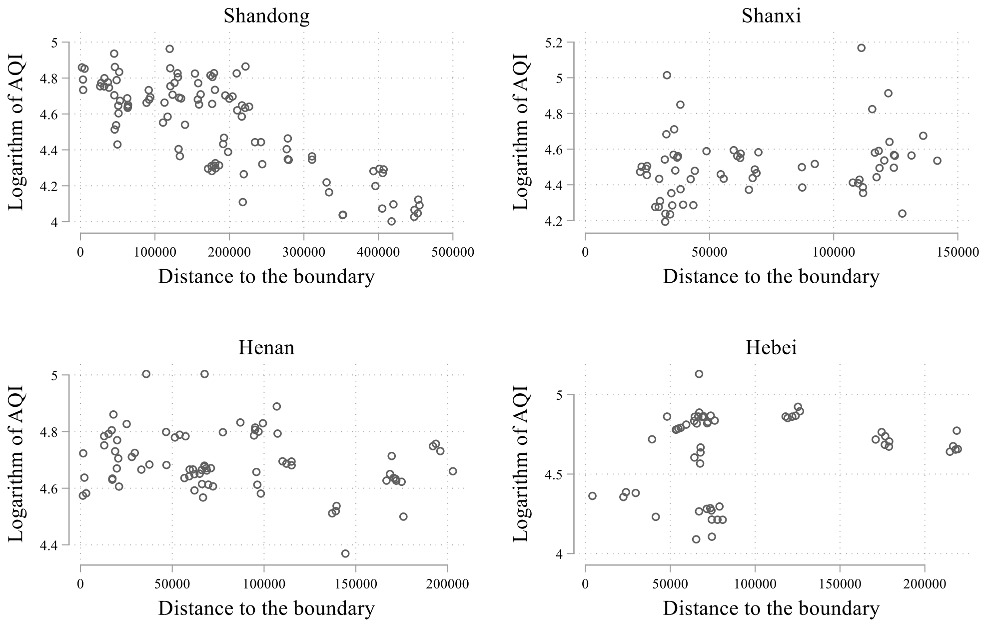

Fig. 5. Scatter plot of AQI and distance to the boundary in four provinces.

The theoretical model presented in Section 3 does not consider geographic factors and assumes flat terrain. Some geographical conditions that are not included in the theoretical model could explain the non-conformity of pollution boundary effects in the Shanxi, Henan, and Hebei Provinces.[9] The Tai-hang Mountains separate Shanxi from Henan and Hebei, and the altitude increases rapidly when approaching the Shanxi-Henan and Shanxi-Hebei boundaries. In general, the economic density decreases with increasing altitude (Zhu et al., 2018), due to the natural disadvantages in high-altitude areas, such as climate deterioration (Nogués-Bravo et al., 2007) and rugged terrain (León and Avilés, 2016). Moreover, the winds at the eastern foot of the Tai-hang Mountains and over the southern Hebei Plain are typically calm, preventing the diffusion of pollutants (Zhu et al., 2011). As a result, the polluting enterprises near Tai-hang Mountains will likely cause excessive local environmental deterioration. Consequently, local governments are less inclined to incentivize polluting enterprises to be located near these boundaries. Our data provide evidence for this explanation. In Appendix Fig. A.1, we distinguish between high- and low-altitude cities with a threshold of 1,000 m. At the boundaries, high-altitude cities have lower pollution levels than low-altitude cities, indicating that high-altitude areas are less attractive for industrial development. Given these geographical characteristics, Henan, Hebei, and Shanxi Provinces are not suitable for investigating the changes in pollution boundary effects. In contrast, Shandong Province, which is located on the flat North China Plain, is less confounded by geographical factors and exhibits significant pollution boundary effects. Therefore, our subsequent analysis focuses solely on Shandong Province.[10]

To further ensure that the distribution of pollution in Shandong Province is not due to better

[9] Due to space constraints, a detailed topographic map is not included in the main text. If readers require the map, please contact the author.

[10] Our model is based on the assumption that all locations have the same productivity and pollution diffusivity, while this is not the same in practice. In the context of local governments taking geographical characteristics into account, the absence of strategic cross-provincial pollution transfers in other provinces also reflects a type of strategic behavior of local governments, which we do not expect to change following the implementation of JAPCP. In this study, we aim to investigate the change of pollution boundary effects after the policy, and thus, our goal is to identify an area exhibiting significant boundary effects. Subsequently, we will provide more evidence to support that the heavier pollution at Shandong boundaries is caused by some intended strategies.

economic development or natural conditions at the boundaries that attract polluting enterprises to agglomerate, we investigated the relationship between the distance to the boundary and certain economic or natural factors in Appendix Table A.2. Columns (1) and (2) demonstrate that GDP does not increase with proximity to the boundary, but rather there is an "inverted U-shaped" relationship of GDP and the distant to the provincial boundary, with the higher economic output located in the inner part of Shandong Province. Moreover, Columns (3) and (4) demonstrate that the distance to the boundary has a significant negative relationship with the population and a significant positive relationship with wind speed. This indicates that boundary areas tend to have a larger population and lower wind speed, implying higher social costs associated with establishing industrial enterprises in this area. Thus, the higher pollution at the boundary is likely caused by factors other than economic development or natural conditions.

Columns (1)–(4) of Appendix Table A.2 include the interactions between distance (and its square) and a time dummy that determines whether the time is after the JAPCP. We find that the estimated coefficients of the interactions are significant but of a very small magnitude. For prudence, we incorporate these factors as control variables in the following regression specification.

4.3. Delimitation of boundaries and descriptive statistics

This study primarily aims to identify the effects of the JAPCP on pollution boundary effects. We expect the JAPCP to affect the policy-covered and policy-uncovered boundaries differently. Therefore, we divided the area of our empirical study into three parts: non-boundary areas, provincial boundaries covered by the JAPCP, and provincial boundaries not covered by the JAPCP.

A boundary county is defined as a county that borders another province or a county adjacent to counties that border another province.[11] This classification is provided in detail in Appendix Table A.4. Subsequently, all atmospheric quality monitoring stations are divided into three groups: provincial boundary stations covered by the JAPCP, provincial boundary stations not covered by the JAPCP, and non-boundary stations. In Shandong Province, a provincial boundary station not covered by the JAPCP refers to a station located in a boundary county with the Shandong-Jiangsu boundaries (JAPCP-uncovered boundaries) as the nearest boundary, and a provincial boundary station covered by the JAPCP refers to a station located in a boundary county with Shandong-Henan or Shandong-Hebei boundaries (JAPCP-covered boundaries) as the nearest boundary. Based on this classification, we have 12 provincial boundary stations covered by the JAPCP, 5 provincial boundary stations not covered by the JAPCP, and 95 non-boundary stations.

Table 1 presents the descriptive statistics for the main variables. The last three columns show the mean of each variable in the non-boundary areas, policy-covered boundaries, and policy-uncovered boundaries, respectively. In Panel A, atmospheric pollution at the provincial boundaries was much greater than that in the non-boundary areas. The variables in Panel C are the number of industrial enterprises above the scale in various industries. The first row in Panel C shows the total number of industrial enterprises in each county. The second to last rows of Panel C present the total number of various heavy-polluting industries in each city, as discussed in detail in Section 6.1. Although the average number of industrial enterprises in non-boundary counties is higher than that in provincial boundary counties, the average number of enterprises in polluting industries in

[11] In China, not every county has an atmospheric quality monitoring station. Very few stations are available for empirical analysis if only the counties that border another province are considered.

provincial boundary counties is mostly larger than that in non-boundary counties.[12] The latter suggests the existence of strategic behavior: local governments tend to permit a larger number of polluting enterprises to be situated at the boundaries, thereby facilitating the transfer of pollution.

Table 1
Descriptive Statistics.

				Mean by location		
	N	Mean	Std. Dev.	Non-boundary	JACPC-covered boundaries	JAPCP-uncovered boundaries
A. Atmospheric quality variables						
AQI	5329	86.50	32.23	82.84	111.0	105.2
$PM_{2.5}$ (μg/m^3)	5328	54.27	28.28	51.28	74.43	69.53
PM_{10} (μg/m^3)	5327	102.1	47.41	96.98	135.7	129.1
CO (μg/m^3)	5319	100.4	48.30	97.00	134.6	97.20
NO_2 (μg/m^3)	5329	35.17	14.64	34.66	38.52	37.86
B. Control variables						
Local GDP (hundred Million CNY)	5329	667.5	470.7	707.1	518.7	250.6
Population (ten thousand)	5329	77.37	31.69	75.30	112.7	48.84
Avg. max. temperature (°C)	5329	19.26	9.831	19.07	20.50	20.30
Avg. min. temperature (°C)	5329	9.925	9.806	9.865	10.10	10.64
Avg. wind speed	5329	2.858	1.009	2.968	2.264	2.029
C. Number of industrial enterprises above the scale						
Industrial enterprise	4778	268.5	217.2	280.5	172.1	239.8
Polluting manufacturing industry	5233	627.4	300.7	622.2	640.4	703.1
Polluting supply industry	5233	39.31	15.78	41.08	26.88	30.42
C25	5233	14.87	18.22	15.18	13.67	11.37
C26	5233	190.3	120.7	188.5	209.5	185.5
C28	5233	5.424	2.589	5.430	5.611	4.895
C29	5233	131.8	83.77	136.5	93.12	120.0
C30	5233	225.6	117.4	219.2	242.8	316.9
C31	5233	32.18	26.66	30.59	47.22	32.00
C32	5233	27.19	15.82	26.79	28.44	32.37

Notes: A unit of observation is a station in a month. Panel A includes monthly atmospheric quality variables. Panel B lists various control variables. The local GDP and population are all yearly data. We calculate the monthly average temperature and wind speed. All control variables are matched to monitoring stations according to the cities located. Panel C shows the numbers of industrial enterprises above scale in various industries. The first row of Panel C is the number of industrial enterprises in each county. The second row to the last row show the number of enterprises in various industries. However, the statistics for various industries in China are only available at the city level; hence, the mean in the second row is larger than that in the first row. The variables based on monitoring stations are merged with the variables based on the city or county where the stations are located. C25 (processing of petroleum, coking, and nucleus fuel), C26 (manufacture of chemical raw material and chemical products), C28 (manufacture of chemical fiber), C29 (manufacture of rubber and plastic), C30 (manufacture of non-metallic mineral products), C31 (manufacture and processing of ferrous metals), C32 (manufacture and processing of non-ferrous metals), D44 (production and supply of electric power and heat power), and D45 (production and supply of gas) are industry codes.

Fig. 6 illustrates the dynamics of the quarterly average AQI in different areas of Shandong Province from 2015 to 2019. In general, the AQI in the three areas exhibits a declining trend. Before the JAPCP (i.e., before March 2017), pollution at the Shandong-Henan or Shandong-Hebei boundary (covered by the JAPCP) is more serious than that at the Shandong-Jiangsu boundary (not covered by the JAPCP). Following the implementation of JAPCP, a significant reduction in pollution levels is observed in non-boundary areas and JAPCP-covered provincial boundaries, particularly during the most polluted quarters (Q1 and Q4) of each year. However, no reduction in pollution levels is observed at JAPCP-uncovered provincial boundaries. On the contrary, there is a

[12] A regression analysis is presented in Columns (5)–(6) of Appendix Table A.2. The results showed that, after controlling for economic and natural factors, areas close to provincial boundary have fewer industrial enterprises, but more polluting industries.

year-on-year increase in pollution during Q4 of 2017, leading to a convergence with, and sometimes even surpassing, the pollution levels at JAPCP-covered provincial boundaries in the subsequent quarters.

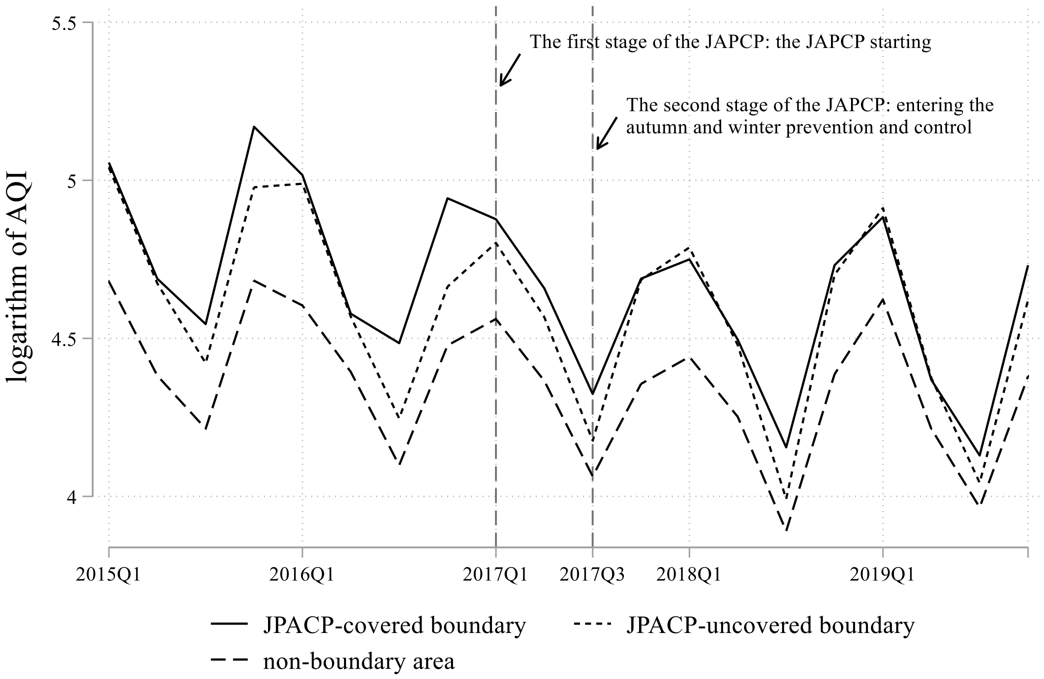

Fig. 6. Quarterly Average AQI in different areas of Shandong Province.

Table 2 shows the percentage change in the number of polluting enterprises in different areas. Since the implementation of the JAPCP, the number of polluting enterprises in non-boundary areas and JAPCP-covered provincial boundaries has decreased, whereas the number of polluting enterprises in JAPCP-uncovered provincial boundaries has predominantly increased, especially those in key regulated industries.[13] Based on our calculations, the percentage change in the numbers of enterprises in key regulated industries in non-boundary areas, JAPCP-covered provincial boundaries, and JAPCP-uncovered provincial boundaries are -15.58%, -25.75%, and 16.71%, respectively, indicating a redistribution of polluting enterprises. Although these facts may be confounded by various factors, the theoretical propositions are supported by this clear pattern.

Table 2
Percentage changes in the number of polluting enterprises in different areas.

			Key regulated industries					Other polluting industries		
	Mfg.	Supply	Total	C26	C28	C29	C32	C25	C30	C31
Non-boundary areas	-19.3%	18.9%	-15.58%	-18.9%	1.6%	-12.7%	-8.2%	1.9%	-19.2%	-58.7%
JAPCP-covered provincial boundaries	-19.0%	27.5%	-25.75%	-30.5%	-21.5%	-15.6%	-20.9%	-20.7%	-9.1%	-16.2%
JAPCP-uncovered provincial boundaries	8.6%	58.7%	16.71%	4.0%	75.9%	25.4%	63.3%	13.2%	5.0%	-31.4%

Notes: This table shows the percentage changes in the average number of enterprises in different industries in different parts of Shandong after the implementation of the JAPCP. The average before the implementation of JAPCP is the average from 2015 to 2016, and the average after the implementation of the JAPCP is the average from 2017 to 2019. The first and second columns refer to all polluting manufacturing industries and all polluting supply industries respectively. The remaining columns refer to specific manufacturing industries discussed in Section 6.1.

[13] Key regulated industries refer to those polluting manufacturing industries focused in the JAPCP. See Section 6.1 for detailed classification.

5. The change in pollution boundary effects

5.1 Baseline estimation

To analyze local governments' strategic responses to the regional environmental policy, we initially investigate the resulting changes in pollution boundary effects using the following difference-in-differences model:

$$\ln AQI_{it} = \beta_0 + \beta_1 Boundary_i \times Post_t + \beta_2 W_{it} + Wind_{i,t} + \mu_i + \eta_t + \varepsilon_{it}, \quad (20)$$

where i and t denote the atmospheric quality monitoring station and month, respectively. $\ln AQI_{it}$ is the logarithm of AQI. $Boundary_i$ is a group dummy, which is set to 1 if the station is at the boundary and 0 otherwise. $Post_t$ is a time dummy indicating policy implementation.[14] W_{it} is a vector of control variables, including the logarithm of local GDP and population, the mean of daily maximum and minimum temperature, and the wind speed. μ_i and η_t denote individual and time fixed effects, respectively. $Wind_{i,t}$ controls the wind direction fixed effect to mitigate the potential influence of wind direction changes on pollution distribution. ε_{it} denotes the error term.

The primary coefficient of interest is β_1, which measures the pollution changes at the boundaries compared to non-boundary areas. Considering that certain policy-covered cities are within non-boundary areas and pollution spillover effects, non-boundary areas do not serve as a control group unaffected by the JAPCP like common DID. β_1 captures the disparity between the JAPCP's influence on boundary and non-boundary areas. As the pollution boundary effects embody the higher pollution at boundaries than in non-boundary areas, β_1 signifies the effect of the JAPCP on pollution boundary effects. According to the above analysis, we expected opposite pollution changes in provincial boundaries covered and not covered by the JAPCP. Two results are presented for each specification: one compares JAPCP-covered provincial boundaries with non-boundary areas and the other compares JAPCP-uncovered provincial boundaries with non-boundary areas.

Table 3 presents the estimation of Equation (20) for the JAPCP-covered boundary, where solely atmospheric quality monitoring stations in the JAPCP-covered boundaries and non-boundary areas are included in the sample. The table includes different classifications: the first three columns adopt the county standard described in Section 4.3 to identify boundary and non-boundary areas, while the following four columns adopt the distance standard. For example, in Column (4), any monitoring station located within 10,000 meters from the boundary is considered a boundary station. By employing various classifications, we demonstrate the robustness of our findings.

Column (1) provides an estimation of the most parsimonious specification, which includes only two-way fixed effects. We find a significantly negative effect of JAPCP on AQI, which indicates that pollution boundary effects decline at JAPCP-covered provincial boundaries. Column (2) provides the results based on the baseline specification, which includes fixed effects for wind direction as well as some weather and socioeconomic variables. The estimated coefficient of Boundary × Post in Column (2) is similar to that in Column (1) and it implies that the policy reduces atmospheric pollution by approximately 9.6% at the boundaries under JAPCP. Given that the

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[14] As mentioned in Section 2.5, the JAPCP has two stages: the first begins in March 2017, and the second begins in October 2017. Nevertheless, the precise phase at which the JAPCP would begin to influence pollution boundary effects is undetermined. We separately evaluate two specifications in the baseline estimation of the JAPCP-uncovered boundary: $Post_t$ equals 1 after March 2017 or October 2017.

average AQI at the boundaries under the JAPCP is approximately 140 in Q1, 2017, this policy effect is considerable. The remaining columns show the robustness results for the baseline specification in column (2).

Table 3
Change in pollution boundary effects at the JAPCP-covered provincial boundaries.

	Log of AQI						
	By county			By distance to the boundaries			
	(1)	(2)	(3)	(4) ≤ 10000	(5) ≤ 30000	(6) ≤ 50000	(7) ≤ 70000
Boundary × Post	-0.091***	-0.096***	-0.096***	-0.066***	-0.066***	-0.097***	-0.094***
	(0.016)	(0.016)	(0.015)	(0.016)	(0.016)	(0.017)	(0.015)
Log of GDP		0.070**	0.052	0.034	0.034	0.055*	0.054*
		(0.031)	(0.032)	(0.033)	(0.033)	(0.031)	(0.032)
Log of population		-0.298***	-0.247***	-0.139*	-0.137	-0.267***	-0.232***
		(0.072)	(0.073)	(0.083)	(0.084)	(0.080)	(0.080)
Avg. max. temp.		0.017***	0.017***	0.018***	0.018***	0.017***	0.017***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Avg. min. temp.		-0.024***	-0.021***	-0.021***	-0.022***	-0.022***	-0.023***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Avg. wind speed		-0.053***	-0.044***	-0.047***	-0.047***	-0.043***	-0.045***
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	No	Yes	No	No	No	No	No
Wind direction × Month FE	No	No	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.903	0.910	0.918	0.918	0.918	0.917	0.917
Observations	4701	4701	4701	4895	4812	4562	4208

Notes: This table investigates the changes in atmospheric pollution at the boundaries under JAPCP. The coefficient of Boundary × Post is the average effect of the JAPCP on the AQI at JAPCP-covered provincial boundaries compared to the non-boundary areas. Columns (1)–(3) use the county standard to distinguish between boundary and non-boundary areas, as described in Section 4.3 (the average distance to the boundaries of the boundary stations is 28,209.39 m), and Columns (4)–(7) use different distance thresholds to distinguish between boundary stations and non-boundary stations. For example, in Column (4), any monitoring station located within 10,000 m of the boundary is considered a boundary station. Each specification includes a constant term, which is not listed in the table. The same applies to the succeeding regression tables. $Post_t$ is set to 1 after March 2017. Robust standard errors clustered at the station level are shown in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

In Table 4, we present the pollution boundary effects at the JAPCP-uncovered provincial boundaries. As mentioned in the institutional background, the JAPCP had two important time points: the initiation of the policy in March 2017 and the commencement of autumn and winter prevention and control in October 2017. In this table, we adjust the time dummy $Post_t$ based on these two time points. In Panel A of Table 4, we set $Post_t$ equal to 1 in March 2017 and thereafter, which is the same as the specification in Table 3. We find that the coefficient of Boundary × Post is no longer statistically different from zero except in Column (4). The significantly positive coefficient in Column (4) may indicate that after the implementation of the JAPCP, pollution initially increases closest to the boundary. Assuming that local governments adopt strategic behaviors, this result is consistent with the idea that closer proximity to the boundary leads to a higher transfer of pollution.

In Panel B of Table 4, we set $Post_t$ equal to 1 in October 2017 (the second important time point) and thereafter. The coefficients of Boundary × Post are positive and significant, except in Column (6). These results imply that the policy does not immediately lead to an increase in pollution at JAPCP-uncovered provincial boundaries, but the policy effect becomes evident after the start of autumn and winter prevention and control. According to Column (2), the JAPCP increases pollution by approximately 4.9% at the JAPCP-uncovered provincial boundaries. In addition, the coefficients of Boundary × Post roughly show a decreasing trend from Columns (4) to (7), supporting the notion of pollution transfer led by the strategic behaviors of the local government.

Table 4
Change in pollution boundary effects at the JAPCP-uncovered provincial boundaries.

	Log of AQI						
	By county			By distance to the boundaries			
	(1)	(2)	(3)	(4) ≤ 10000	(5) ≤ 30000	(6) ≤ 50000	(7) ≤ 70000
A. Setting Post = 1 after March 2017.							
Boundary × Post	-0.003	0.000	0.000	0.039***	-0.024	-0.027*	-0.008
	(0.018)	(0.014)	(0.017)	(0.009)	(0.029)	(0.015)	(0.013)
Log of GDP		0.070**	0.052	0.034	0.034	0.055*	0.054*
		(0.031)	(0.032)	(0.033)	(0.033)	(0.031)	(0.032)
Log of population		0.086***	0.062*	0.033	0.033	0.060*	0.063**
		(0.031)	(0.031)	(0.033)	(0.033)	(0.031)	(0.031)
Avg. max. temp.		0.017***	0.017***	0.018***	0.018***	0.017***	0.017***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
Avg. min. temp.		-0.406***	-0.291**	-0.118	-0.115	-0.292**	-0.296**
		(0.141)	(0.138)	(0.083)	(0.083)	(0.136)	(0.136)
Avg. wind speed		-0.053***	-0.044***	-0.047***	-0.047***	-0.043***	-0.045***
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.008)
Adj. R^2	0.899	0.907	0.915	0.917	0.917	0.915	0.915
B. Setting Post = 1 after October 2017.							
Boundary × Post	0.051**	0.049***	0.053***	0.082***	0.060**	0.008	0.034**
	(0.022)	(0.016)	(0.018)	(0.011)	(0.024)	(0.021)	(0.014)
Log of GDP		0.083***	0.059*	0.033	0.033	0.059*	0.056*
		(0.031)	(0.031)	(0.033)	(0.033)	(0.031)	(0.031)
Log of population		-0.409***	-0.292**	-0.119	-0.122	-0.284**	-0.260*
		(0.140)	(0.137)	(0.083)	(0.083)	(0.137)	(0.138)
Avg. max. temp.		0.020***	0.019***	0.018***	0.018***	0.019***	0.019***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Avg. min. temp.		-0.025***	-0.021***	-0.022***	-0.022***	-0.022***	-0.022***
		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Avg. wind speed		-0.055***	-0.044***	-0.048***	-0.047***	-0.043***	-0.044***
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Adj. R^2	0.899	0.907	0.915	0.917	0.917	0.915	0.915
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	No	Yes	No	No	No	No	No
Wind direction × Month FE	No	No	Yes	Yes	Yes	Yes	Yes
Observations	4499	4499	4499	4812	4812	4553	4499

Notes: This table investigates the changes in atmospheric pollution at the JAPCP-uncovered provincial boundaries. According to the standard distinguishing counties in boundary and non-boundary areas, the mean value of the distance from boundary counties to the JAPCP boundary is 30,903.03 m. Panels A and B have different settings for time dummy $Post_t$, reflecting that JAPCP has two commencement dates. In Panel A, $Post_t$ is set to 1 after March 2017, while in Panel B, it is set to 1 after October 2017.
***p < 0.01; **p < 0.05; *p < 0.1.

As shown in Table 3 and Table 4, the JAPCP mitigates pollution at JAPCP-covered provincial boundaries while worsening pollution at JAPCP-uncovered provincial boundaries. Quantitative analysis reveals the amount of pollution increase at JAPCP-uncovered provincial boundaries is lower than the decrease at JAPCP-covered provincial boundaries, which implies that the JAPCP has resulted in an overall reduction in atmospheric pollution. However, it should be noted that ignoring pollution transfer across provincial boundaries will lead to an overestimation of the pollution reductions achieved by the JAPCP.

To further ensure the reliability of the baseline results, we re-estimate and report the results in Appendix Table A.5 using the PSM-DID method. All three samples, based on radius matching of 1%, kernel matching (Epanechnikov kernel), and one-to-one matching, show similar results to the baseline model. Besides, we use the concentrations of different atmospheric pollutants (PM2.5, PM10, CO, and NO2) as dependent variables to address the concern about the measurement of atmospheric pollution. According to Table A.6, all estimated coefficients have the same sign as the baseline results. Moreover, we conduct a falsification test using the three other provinces (Shanxi, Henan, and Hebei). As we do not observe pollution boundary effects in these provinces, any significant change in the relative pollution at the boundaries should not be observed. In Table A.7, we find that all coefficients are not significant. Finally, we mitigate the potential impact arising from the "Beijing effect," which suggests that the JAPCP might intend to relocate pollutants away from Beijing to alleviate its pollution burden. To achieve this, we introduce an interaction term between the distance from Beijing and the policy time point. The results are presented in Table A.8, where we find a minimal reduction in the coefficient of the DID estimator and its significance persists.

5.2. Long-term effects

Given that the JAPCP's effect is long-lasting rather than transient, we are interested in its longer-term progressive effects. Therefore, we employ the following event study:

$$\ln AQI_{it} = \rho_0 + \sum_{k=-8}^{13} \delta_k \times Treat_i \times I_{kt} + \gamma W_{it} + Wind_{i,t} + \mu_i + \eta_t + \varepsilon_{it}, \tag{21}$$

where I_{kt} represents a series of time dummies. We use I_{-8t} to denote July 2016 and before and use I_{13t} to denote April 2018 and thereafter. I_{-7t} to I_{12t} denote each month from August 2016 (the seventh month before the policy) to March 2018 (the twelfth month after the policy). The other variables in Equation (21) have the same definitions as those in Equation (20). In this specification, $\{\delta_0, \delta_1, \ldots, \delta_{13}\}$ captures the long-term effects of the JAPCP on boundary pollution.

Fig. 7 shows the dynamics by plotting the event study coefficients obtained by estimating Equation (21). At the JAPCP-covered provincial boundaries, there is a relatively flat pre-trend before JAPCP and a salient reduction in pollution after JAPCP, which persists in the following periods. In line with the results in Table 4, we do not find immediate effects at the JAPCP-uncovered provincial boundaries. However, after the implementation of the autumn and winter prevention and control in October 2017, the estimated coefficients become significantly positive and sizable.

Considering the seasonal variation of pollution, it would be more appropriate to compare the autumn/winter of 2016 with the autumn/winter of 2017. Notably, during the autumn/winter of 2016, the coefficient of both boundaries follows a similar trajectory with statistically insignificant point estimates. During the autumn/winter of 2017, however, distinct tendencies emerge between the JAPCP-covered and JAPCP-uncovered boundaries. This finding implies that the change in pollution boundary effects is not due to natural factors.

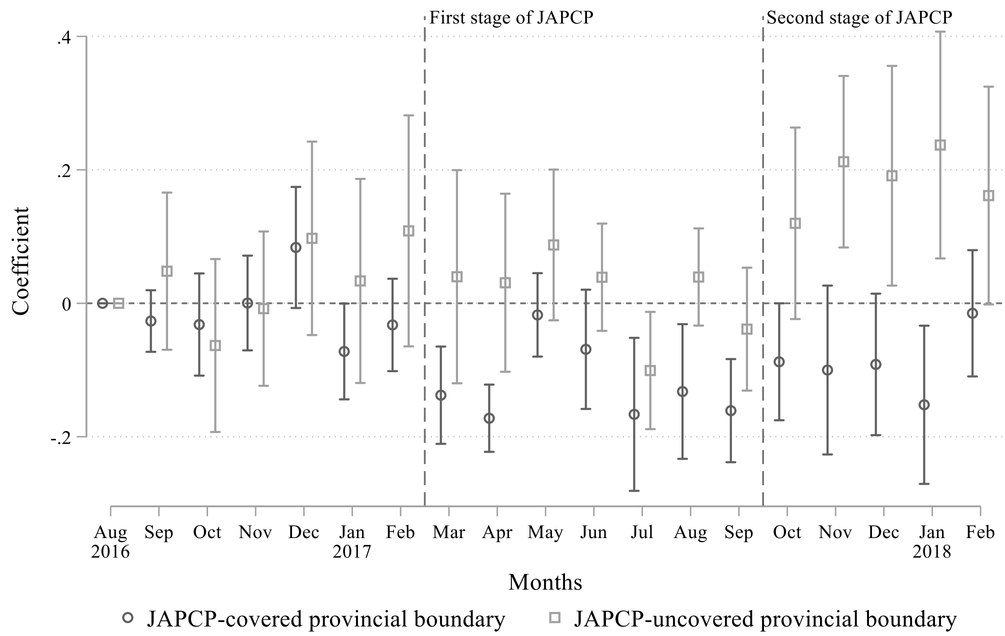

Fig. 7. Long-term effects on boundary effects of JAPCP.

6. Mechanisms

As noted in Section 2.2, environmental regulations in China are frequently captured by political interests. Local governments often interfere with enforcing environmental departments to achieve their own goals. Consequently, alterations in environmental regulations can influence the distribution of polluting enterprises, leading to changes in boundary effects. In this section, the following regression model is used to identify these mechanisms:

$$Y_{it} = \alpha_0 + \alpha_1 Boundary_i \times Post_t + \alpha_2 W_{it} + \mu_i + \eta_t + Wind_{i,t} + \varepsilon_{it}. \quad (22)$$

This specification is identical to Equation (20), with the exception that the dependent variables are replaced by the logarithm of the number of enterprises or environmental regulation intensities. Although we only have access to annual data for industrial enterprises and environmental regulations, we maintain a monthly panel structure for the estimates in this section to ensure consistency with the prior specifications. Therefore, the variable values for each month are filled with the values that correspond to the corresponding year. In this section, the variable $Post_t$ is set to 1 after March 2017 unless otherwise specified. Although unreported, qualitative results obtained using the alternative definition of $Post_t$ (after October 2017) are generally consistent.

6.1. Changes in the distribution of polluting enterprises

We initiate the analysis by focusing on the overall number of industrial enterprises, and the estimation results are presented in Table 5. Panel A considers the changes at JAPCP-covered provincial boundaries (i.e., the sample in Panel A contains only stations at JAPCP-covered provincial boundaries and non-boundary areas like Table 3), and Panel B considers those at JAPCP-uncovered provincial boundaries. The estimated coefficient of Boundary × Post in Column (1) of Panel A indicates that JAPCP leads to a 29.1% decrease in the number of total industrial enterprises at JAPCP-covered provincial boundaries compared to the non-boundary areas, and the estimated coefficient in Panel B indicates a slight decrease in industrial enterprises at JAPCP-uncovered provincial boundaries without statistical significance.

We further categorize enterprises based on two criteria: the industrial criterion, which categorizes them as heavy or light industrial enterprises, and the size criterion, which categorizes them as large, medium, small, or micro-sized industrial enterprises.[15] The estimated coefficients of Boundary × Post at the JAPCP-covered provincial boundaries are all negative, but most of them are insignificant. In Panel B, there is no discernible pattern in the estimated coefficients of Boundary × Post for JAPCP-uncovered boundaries. These results imply that the JAPCP may not have a deterministic impact on the aggregate number of industrial enterprises. Consequently, we undertake a more comprehensive examination of the effects that JAPCP has imposed on the industrial structure.

Table 5
The redistribution of industrial enterprises.

	All	Heavy	Light	Large	Medium	Small/Micro
	(1)	(2)	(3)	(4)	(5)	(6)
A. JAPCP-covered provincial boundaries						
Boundary × Post	-0.291***	-0.090	-0.019	-0.039	-0.049**	-0.062
	(0.126)	(0.096)	(0.064)	(0.032)	(0.021)	(0.082)
Adj. R^2	0.955	0.964	0.971	0.936	0.968	0.956
Observations	4326	4266	4266	4470	4470	4506
B. JAPCP-uncovered provincial boundaries						
Boundary × Post	-0.049	-0.008	0.030**	-0.069	-0.152***	0.011
	(0.036)	(0.032)	(0.014)	(0.103)	(0.014)	(0.013)
Adj. R^2	0.967	0.972	0.973	0.935	0.966	0.960
Observations	3998	4171	4171	4378	4378	4378
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The explained variables for each column are the logarithms of the total number of industrial enterprises, heavy industrial enterprises, light industrial enterprises, large-, medium-, and small- and micro-sized industrial enterprises. Robust standard errors clustered at the station level are shown in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

The examination of industrial structure derives from JAPCP's two objectives: one requires local governments to rectify small manufacturing and processing enterprises, and the other requires reducing coal use and eliminating coal-fired boilers. Hence, this policy primarily focuses on polluting manufacturing and energy supply enterprises. Based on Liu and Liu (2015), we classify C25 (processing of petroleum, coking, and nucleus fuel), C26 (manufacture of chemical raw material and chemical products), C28 (manufacture of chemical fiber), C29 (manufacture of rubber and plastic), C30 (manufacture of non-metallic mineral products), C31 (manufacture and processing of ferrous metals), C32 (manufacture and processing of non-ferrous metals) as polluting manufacturing industries and D44 (production and supply of electric and heat power) and D45 (production and supply of gas) as polluting supply industries.[16] According to the JAPCP document, C26, C28, C29, and C32 are classified as key regulated industries, while C25, C30, and C31 are

[15] According to the official classification criteria, heavy industrial enterprises refer to enterprises in industries that provide the material and technical foundation for all sectors of the national economy, and light industrial enterprises are ones that mainly provide consumer goods and make hand tools. Large-sized industrial enterprises refer to those with more than 1,000 employees and more than 400 million CNY operating income. In the remaining, those with more than 300 employees and more than 20 million CNY operating income are medium-sized enterprises, and the others are small- and micro-sized enterprises.
[16] The industry codes C25, C26, etc. are introduced by the China Securities Regulatory Commission in 2012. For simplicity, we use these codes to denote the respective industries in the subsequent paragraphs.

classified as other polluting industries.[17]

Table 6 presents estimates of the changes in the number of enterprises aggregated across specific industries. Columns (1) and (2) indicate that the JAPCP does not lead to a change in the number of polluting manufacturing and supplying industry enterprises at JAPCP-covered provincial boundaries. However, Columns (3) and (4) show that, after the implementation of the JAPCP, the enterprises in polluting manufacturing and supplying industries at JAPCP-uncovered provincial boundaries increase by 2.3% and 3.6%, respectively.

Table 7 investigates the variation in the number of industry enterprises based on JAPCP's target, wherein Columns (1) to (5) present the four key regulated industries, while Columns (6) to (9) present three other polluting manufacturing industries.[18] A discernible pattern can be identified throughout these categories. At the JAPCP-covered provincial boundaries, there is a 15.6% decrease in the total number of enterprises in key-regulated industries whereas a 13.4% increase in the total number of enterprises in other polluting industries. Conversely, Panel B shows a 6.6% increase in the total number of enterprises in key regulated industries and insignificant change in the total number of enterprises in other polluting industries. The results demonstrate that the total number of enterprises and the number of enterprises in each of the four key regulated industries exhibit the same changing trend.[19] The seemingly unrelated estimations show that there are significant differences in the coefficients in each column of Panels A and B.[20]

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[17] The JAPCP document outlines its policy targeting on "small manufacturing and processing enterprises involved in various industries including non-ferrous metal smelting and processing, rubber production, tanning, chemical, ceramic firing, casting, silk screen processing, steel rolling, refractory materials, carbon production, lime kilns, brick kilns, cement grinding stations, waste plastic processing, printing utilized paints, inks, adhesives, and organic solvents, as well as furniture manufacturing." Hence, C26, C28, C29, and C32 are classified as key regulated industries. The original policy document for the first stage is no longer accessible on the MEE official website at the time of writing. It is available from the authors upon request.

[18] In Table A.9 of the Appendix, we simply regress the AQI on the number of enterprises in different industries to provide indirect support for this classification. The results show that enterprises in all four key industries have a significantly positive correlation with pollution (except that C28 is not significant but still positive). For example, the estimated coefficient of C26 is 0.323 (s.e. = 0.049). Regarding other polluting industries, the coefficient of C25 is much less (0.143, s.e. = 0.030), while negative and insignificant correlations are observed between atmospheric pollution and enterprises in C30 (-0.100, s.e. = 0.133) and C31 (-0.029, s.e. = 0.026).

[19] Although the number of C28 enterprises at JAPCP-uncovered provincial boundaries has decreased, the correlation between C28 and atmospheric pollution is weak. Refer to Table A.9 of the Appendix.

[20] To further ensure that the increase of polluting enterprises at the JAPCP-uncovered boundaries is not due to the changes in some natural factor that facilitates pollution diffusion (e.g., the wind direction change after the policy), we investigate the polluting enterprises at the boundaries of Jiangsu Province in Table A.10. If the change observed at the JAPCP-uncovered boundaries is due to the natural factors, we would expect to see a decrease of polluting enterprises at the boundary of Jiangsu province; however, this is not evident in our findings.

Table 6
Changes in the number of enterprises in polluting manufacturing and supply industries.

	JAPCP-covered provincial boundaries		JAPCP-uncovered provincial boundaries	
	Manufacturing	Supply	Manufacturing	Supply
	(1)	(2)	(3)	(4)
Boundary × Post	-0.030	0.025	0.023*	0.036*
	(0.027)	(0.053)	(0.014)	(0.020)
Control variables	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes
Adj. R^2	0.954	0.934	0.960	0.939
Observations	4656	4656	4426	4426

Notes: The dependent variables in Columns (1) and (3) are the logarithms of the number of polluting manufacturing industry enterprises and those in Columns (2) and (4) are the logarithms of the number of polluting supply industry enterprises. Columns (1) and (2) compare the JAPCP-covered provincial boundaries with non-boundary areas, and Columns (3) and (4) compare the JAPCP-uncovered provincial boundaries with non-boundary areas. Robust standard errors clustered at the station level are shown in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

The results above can be summarized as an industry-specific relocation of polluting enterprises, with the overall number remaining relatively stable. On the one hand, the exit of high-polluting enterprises and the entry of less-polluting enterprises result in decreased atmospheric pollution at the JAPCP-covered provincial boundaries. On the other hand, the entry of high-polluting enterprises leads to an increase in atmospheric pollution at the JAPCP-uncovered provincial boundaries. Thus, the opposite changes in pollution between the JAPCP-covered and JAPCP-uncovered provincial boundaries can be partly attributed to the redistribution of polluting enterprises.

Table 7

Changes in the numbers of enterprises in key industries and other industries.

	Key regulated industries					Other industries			
	Total	C26	C28	C29	C32	Total	C25	C30	C31
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
B. JAPCP-covered provincial boundaries									
Boundary × Post	-0.156***	-0.148***	-0.414***	-0.121*	-0.214***	0.134***	-0.347***	0.116***	0.372**
	(0.034)	(0.030)	(0.133)	(0.062)	(0.055)	(0.031)	(0.068)	(0.030)	(0.160)
Adj. R^2	0.942	0.940	0.847	0.940	0.939	0.933	0.982	0.933	0.852
Observation	4656	4656	4526	4656	4656	4656	4449	4656	4656
B. JAPCP-uncovered provincial boundaries									
Boundary × Post	0.066*	0.084*	-0.160***	0.082*	0.148***	0.016	-0.083***	0.038	-0.310
	(0.039)	(0.047)	(0.030)	(0.048)	(0.037)	(0.037)	(0.020)	(0.038)	(0.207)
Adj. R^2	0.949	0.940	0.875	0.951	0.943	0.939	0.987	0.937	0.839
Observation	4426	4426	4234	4426	4426	4426	4219	4426	4426
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SUE chi-sq	23.71	27.88	3.74	8.00	43.75	10.38	16.52	4.47	7.99

Notes: The dependent variable in each column is the logarithm of the number of enterprises in different industries. We refer to C26, C28, C29, and C32 as key regulated industries and C25, C30, and C31 as other industries. See Section 6.1 for details. In each column, we use the seemingly unrelated estimation to test whether the estimated coefficients in Panels A and B are statistically equal, and the last row reports the chi-sq. Robust standard errors clustered at the station level are shown in parentheses.

***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Following Zou (2021), we employ a diverse range of industries to further comprehend how the policy works through enterprises. The aforementioned coefficient estimates are summed in Fig. 8, which also incorporates estimations for additional low-polluting industries in our samples. The coefficients for JAPCP-covered and JAPCP-uncovered boundaries are shown in each row of the figure. It is evident that the JAPCP-uncovered provincial boundaries do not exhibit any significant positive effect in low-pollution industries. Key regulated industries exhibit a predominant declining trend at the JAPCP-covered boundary and a rising trend at the JAPCP-uncovered boundary. Low-polluting industries, on the contrary, exhibit predominant downward trends at both boundaries. These findings indicate that industry-specific strategic behaviors are the driving forces behind the changes in industrial structure.

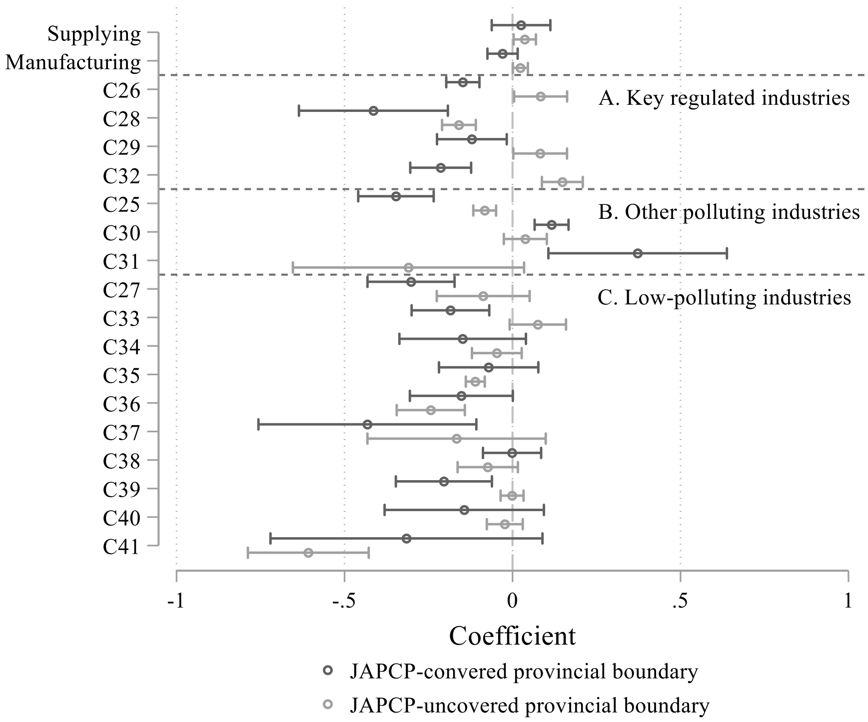

Fig. 8. Policy effects on the number of enterprises by industries.

6.2. Changes in the environmental regulation intensity

Several studies have indicated that local governments influence firms' distribution and production activities through differentiated environmental regulation intensities (Cai et al., 2016; He et al., 2020). In this subsection, we investigate the influence of JAPCP implementation on the environmental regulation intensities at two distinct boundaries. To assess environmental regulation intensities, we collect the annual government work reports of each city during the sample period and calculate the number of words related to environmental protection per 10,000 words in these reports.

The optimal approach involves investigating changes in word frequencies for specific keywords related to atmospheric pollution. However, less than 80% of the reports incorporated the term "daqi" (atmosphere), and approximately half of the reports featured the term more than once. Only 62.5% of the reports included the term "daqiwuran" (atmospheric pollution), and merely 28.8%

of the reports had the term appear more than once. Due to the extremely low word frequencies, it is difficult to accurately capture the reduction of specific words. Hence, we have abstained from using keywords directly related to atmospheric pollution. Instead, we calculate the frequency of three keywords: “huanjing” (environment), “huanbao” (environmental protection), and “wuran” (pollution). These three words appear 16.49, 4.08, and 6.85 times on average in each report, respectively.

Table 8 presents the estimated results. The frequency of environment-related keywords in government work reports at the JAPCP-uncovered boundaries has decreased significantly by 9.07 occurrences (4.43 per 10,000 words) since the implementation of the JAPCP. Specifically, the frequency of the keywords “huanjing,” “huanbao,” and “wuran” has decreased by 1.46, 1.64, and 1.32 times per 10,000 words, respectively. On the contrary, at the JAPCP-covered boundaries, positive estimated coefficients are observed for the total keywords, albeit without statistical significance.

These findings signify a decline in environmental regulation intensities at the JAPCP-uncovered boundaries, aligning with the relocation of polluting enterprises to those areas. This is in keeping with the theoretical analysis in the preceding subsection. Due to the inherent limitations of assessing environmental regulation intensity, we face challenges in providing evidence on the industry-specific feature of government strategic behavior.

Table 8
Changes in the environmental regulation intensities.

	Frequency				Frequency per 10000 words			
	Total	"huanjing"	"huanbao"	"wuran"	Total	"huanjing"	"huanbao"	"wuran"
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A. JAPCP-covered provincial boundaries								
Boundary × Post	0.410	1.465	0.267	-1.321	0.846	1.556	0.156	-0.866
	(3.674)	(2.724)	(0.354)	(0.897)	(2.358)	(1.691)	(0.259)	(0.603)
Adj R^2	0.634	0.668	0.654	0.441	0.553	0.473	0.668	0.463
Observations	4705	4705	4705	4705	4705	4705	4705	4705
B. JAPCP-uncovered provincial boundaries								
Boundary × Post	-9.065***	-4.021***	-2.751***	-2.293**	-4.425***	-1.458***	-1.644***	-1.323**
	(1.169)	(0.656)	(0.332)	(1.091)	(0.484)	(0.342)	(0.238)	(0.548)
Adj R^2	0.640	0.688	0.680	0.430	0.543	0.509	0.688	0.451
Observations	4505	4505	4505	4505	4505	4505	4505	4505
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table examines the change in environmental regulation intensities at different boundaries after the JAPCP by regressing the frequency of some keywords related to environmental protection in government work reports. "Huanjing," "huanbao," and "wuran" refer to "environment," "environmental protection," and "pollution," respectively. Robust standard errors clustered at the station level are shown in parentheses.
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

6.3. Supplementary test for local government's strategic behavior

The changes in pollution boundary effects and the underlying mechanism were illustrated in the preceding estimations; in this subsection, we conduct additional robustness tests on the strategic behaviors of the local government. While the JAPCP covers several cities in the non-boundary area of Shandong, it does not cover all of them. As the relocation of polluting enterprises, the decrease in boundary effects at JAPCP-covered provincial boundaries may be due to the incomplete coverage of the policy in non-boundary areas. Similarly, as some non-boundary areas are covered by JAPCP, directly comparing the atmospheric pollution between JAPCP-uncovered provincial boundaries and non-boundary areas may result in an overestimation of the effect of the local government's strategic behavior.

To address these concerns, we delete the observations of non-boundary areas uncovered by JAPCP when estimating the impact of JAPCP on pollution boundary effects at JAPCP-covered provincial boundaries, and delete the observations of non-boundary areas covered by JAPCP when estimating the impact of JAPCP on pollution boundary effects at JAPCP-uncovered provincial boundaries. By using the adjusted samples and comparing the results to earlier ones, we can separate the effects of the strategic behavior with comparatively higher precision.

Table 9 displays the re-estimated results. For comparison, estimates using the baseline sample for each regression are also provided in the table. In Column (1), the relative change in the logarithm of AQI is reported. As expected, the estimated coefficient of JAPCP-covered boundaries decreases from -0.096 to -0.06 using the adjusted sample, while maintaining its significance and sign. The coefficient of JAPCP-uncovered boundaries exhibits a slight decrease from 0.049 to 0.042. These findings imply that, although both are located in policy-covered regions, boundary areas receive more environmental attention from local governments than non-boundary areas. In regions not covered by the regional policy, local governments are more likely to engage in spatially opportunistic behavior at boundary areas.

Taking into account the spillover effect of clear air, the positive estimate in Column (1) of Panel B may still be attributed to the closer distance between non-boundary and JAPCP-covered areas. To address this concern, the adjusted sample is utilized in Columns (2) to (5) to re-estimate the changes in the number of polluting enterprises and environmental regulation intensities.[21] The estimated coefficients in the majority of regressions are even more significant than those from the baseline sample. These estimates exhibit the same discernible pattern as observed in the preceding sections. This regional policy incentivizes local governments to impose increasing regulatory intensities (although the estimate remains insignificant) to reduce the number of polluting enterprises at JAPCP-covered boundaries, especially in key regulated industries. This can be perceived as "window dressing." Simultaneously, more lenient regulation intensities are employed to attract polluting enterprises to locate in JAPCP-uncovered boundaries. Although the relocation of enterprises inherently results in spillover effects, it is beyond the scope of this study to provide a precise estimate of this. Instead, this study seeks to highlight the potential spatial opportunistic behavior of local governments in response to regional environmental policies, which can be

[21] As introduced in Section 6.1, four industries (C26, C28, C29, and C32) are classified as key regulated industries. Here, we aggregate their numbers and use the logarithm as the dependent variable in Column (4). Additionally, we aggregate the counts of three environment-related keywords ("huanjing," "huanbao," and "wuran") as the dependent variable in Column (5). Detailed estimates for each industry and keyword are reported in Tables Table A.11 and Table A.12 of the Appendix, and they are largely consistent with the qualitative findings from the baseline sample.

observed by examining the differences in specific industry enterprises and the environmental regulation intensities at the two boundaries.

Table 9
Re-estimating the main results using the adjusted sample.

	AQI	Manufacturing industry	Supply industry	Key regulated industry	Regulation Intensity
	(1)	(2)	(3)	(4)	(5)
A. JAPCP-covered provincial boundary					
Boundary × Post	-0.060***	-0.186***	-0.071	-0.197***	2.471
	(0.019)	(0.034)	(0.062)	(0.035)	(2.394)
Baseline estimate	-0.096***	-0.030	0.025	-0.156***	0.846
Adj. R^2	0.924	0.863	0.906	0.916	0.509
Observation	1665	1635	1635	1635	1665
B. JAPCP-uncovered provincial boundary					
Boundary × Post	0.042***	0.066***	0.054***	0.048*	-5.163***
	(0.016)	(0.014)	(0.016)	(0.028)	(0.624)
Baseline estimate	0.049***	0.023*	0.036*	0.066*	-4.425***
Adj. R^2	0.899	0.968	0.965	0.970	0.581
Observation	3279	3230	3230	3230	3279
Controls	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes

Notes: This table uses the adjusted samples to reestimate the main results. The stations not covered by the JAPCP are deleted in Panel A, and the stations covered by the JAPCP are deleted in Panel B. To keep with the prior specification, in Column (1), variable $Post_t$ is set to 1 after March 2017 in Panel A and after October 2017 in Panel B. In the remaining columns, $Post_t$ is set to 1 after March 2017. The row "Baseline estimates" presents estimates using the baseline sample. Robust standard errors clustered at the station level are shown in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

7. Conclusion

Some countries have implemented regional environmental policies to reduce pollutant emissions. Nevertheless, the existing literature focuses more on the overall effects of these regional environmental policies, ignoring the spillover effects of regional environmental policies on areas not covered by these policies. This study reveals that the strategic behaviors of local governments, which are manifested in transferring pollution sources to boundary areas not covered by regional environmental policies through differentiated environmental regulation intensities, can partly undermine the aggregate effects of these policies. Therefore, policymakers must consider the spillover effects and local governments' strategic responses when designing regional environmental policies.

In this study, we develop a model to explain the strategic behavior of local governments after implementing regional environmental policies. Considering that local governments have dual incentives for environmental protection and economic growth in the Chinese-style decentralization system, they may adopt strategic behaviors to intensify regulation enforcement in the inland area of jurisdiction, while relaxing regulation enforcement at the boundaries of jurisdiction. If only a part of the jurisdiction is covered by a particular regional environmental policy, the local government may encourage the transfer of pollution sources from policy-covered jurisdictions to policy-uncovered jurisdictions, especially to the boundaries not covered by the policy.

Using atmospheric quality panel data from monitoring stations in China, we examine the comprehensive policy effects of the JAPCP in Beijing, Tianjin, and 26 cities in the Hebei, Henan, Shandong, and Shanxi Provinces starting in 2017. Owing to geographical characteristics, we confined our empirical study to Shandong Province. The empirical results are in accordance with the theoretical analysis. Using the difference-in-differences method, we identify the change in pollution boundary effects at JAPCP-covered and JAPCP-uncovered provincial boundaries, respectively. The results show that compared with non-boundary areas, the policy results in a 9.6% reduction in AQI at the JAPCP-covered provincial boundaries but a 5.3% increase in AQI at JAPCP-uncovered provincial boundaries. In addition, the closer to the JAPCP-uncovered provincial boundaries, the greater the increase in AQI. For example, the policy led to an 8.2% increase in AQI within the 10,000 m bandwidth of the JAPCP-uncovered provincial boundaries.

We also investigate the change in the distribution of polluting enterprises to shed light on the mechanism of changes in pollution boundary effects. Although the total number of industrial enterprises declined at both JAPCP-covered and JAPCP-uncovered provincial boundaries, the industrial structure of the JAPCP-uncovered provincial boundaries changed. At the JAPCP-uncovered provincial boundaries, although the number of enterprises in other industries decreased, the number of enterprises in key regulated industries significantly increased. This phenomenon strongly implies the possible existence of industry-specific strategic behaviors by the local government. Through keyword frequency analysis of the government work reports, we find that the local government reduced environmental regulation intensities at the JAPCP-uncovered boundaries.

This study carries several policy implications. In decentralized countries where local governments typically offer multiple incentives, it is common for local governments to strategically respond to regional environmental policies. If the policy is implemented only in certain parts of a jurisdiction, local governments may devote extra attention to the areas covered by the policy at the expense of others. Although the regional environmental policy is beneficial for reducing pollution in policy-covered areas, local governments may adopt countermeasures to steer polluting enterprises to boundaries uncovered by policy, which becomes an obstacle to achieving the original goal of reducing pollution nationwide. To improve the effectiveness of regional environmental policies, the central government should focus on the following aspects. First, incentives that conflict with environmental governance should be reduced in decentralized systems. Second, the central government should consider the strategic responses of local governments when determining environmental decentralized structures and designing regional environmental policies. Third, the central government should supervise the relocation of polluting enterprises from the policy-covered to policy-uncovered areas and make every effort to control boundary pollution between administrative divisions.

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Appendix A: Supplemental figures and tables

Appendix A contains supplementary figures and tables corresponding to the main body.

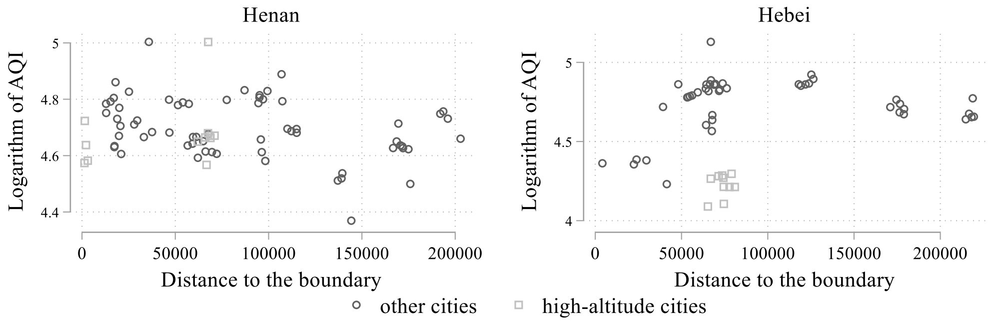

Fig. A.1. Atmospheric quality in cities with different altitudes in Henan and Hebei.

Table A.1
Relationship between AQI and distance to the boundary in four provinces.

	Logarithm of AQI			
	Shandong	Shanxi	Henan	Hebei
	(1)	(2)	(3)	(4)
Logarithm of distance to the boundary	-0.156***	0.055*	-0.007	0.111***
	(0.023)	(0.029)	(0.012)	(0.023)
Observations	2463	1430	1926	1353
Adj. R^2	0.659	0.630	0.798	0.471

Notes: The samples in this table are from January 2015 to February 2017 (before the JAPCP). The month fixed effects are controlled for each regression analysis. Robust standard errors clustered at the station level are present in parentheses.
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table A.2
The relationship between the distance to the boundary and some economic or natural factors.

	GDP		Population	Wind speed	Industrial enterprise	Polluting mfg. industry
	(1)	(2)	(3)	(4)	(5)	(6)
Distance	-0.006	0.067***	-0.012***	0.046***	3.965*	-5.095*
	(0.004)	(0.011)	(0.003)	(0.003)	(2.035)	(2.983)
Distance^2		-0.002***				
		(0.000)				
Distance × Post	-0.000	-0.015**	0.002*	-0.009***		
	(0.002)	(0.006)	(0.001)	(0.002)		
Distance^2 × Post		0.0003***				
		(0.0001)				
GDP					229.605***	226.561***
					(57.673)	(71.181)
Population					155.725**	-117.868
					(66.927)	(99.783)
Wind speed					30.868	-39.164
					(25.928)	(54.045)
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.115	0.259	0.130	0.713	0.510	0.202
Observations	4944	4944	5082	5396	1712	1930

Notes: This table investigates the relationship between the distance to the boundary and some economic or natural factors before the policy was implemented. To prevent the estimated coefficient from being too small, we set the distance unit to 10 km. The GDP and population in this table are in logarithmic form. Columns (5) and (6) contain only samples before 2017. See Section 6.1 for the detailed classification of polluting manufacturing industries in column (6). All regressions include constant terms that are not listed in the table. Robust standard errors clustered at the station level are present in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Table A.3
JAPCP "2+26" cities.

"2":
Beijing (北京市), Tianjin (天津市).
"26":
Hebei Province (河北省): Shijiazhuang (石家庄市), Tangshan (唐山市), Langfang (廊坊市), Baoding (保定市), Cangzhou (沧州市), Hengshui (衡水市), Xingtai (邢台市), Handan (邯郸市).
Shanxi Province (山西省): Taiyuan (太原市), Yangquan (阳泉市), Changzhi (长治市), Jincheng (晋城市).
Shandong Province (山东省): Jinan (济南市), Zibo (淄博市), Jining (济宁市), Dezhou (德州市), Liaocheng (聊城市), Binzhou (滨州市), Heze (菏泽市).
Henan Province (河南省): Zhengzhou (郑州市), Kaifeng (开封市), Anyang (安阳市), Hebi (鹤壁市), Jiaozuo (焦作市), Xinxiang (新乡市), Puyang (濮阳市).

Notes: This table lists the "2+26" cities, where "2" represents Beijing and Tianjin and "26" represents 26 cities in four provinces.

Table A.4
Classification of boundary and non-boundary counties.

A. Non-boundary areas
Weihai (威海市): Rushan (乳山区), Wendeng (文登市), Huancui (环翠区), Rongcheng (荣成市).
Rizhao (日照市): Donggang (东港区).
Dongying (东营市): Dongying (东营区).
Linyi (临沂市): Lanshan (兰山区).
Zaozhuang (枣庄市): Shanting (山亭区), Shizhong (市中区).
Taian (泰安市): Taishan (泰山区).
Jinan (济南市): Lixia (历下区), Licheng (历城区), Tianqiao (天桥区), Shizhong (市中区), Huaiyin (槐荫区), Zhangqiu (章丘市), Laiwu (莱芜区), Changqing (长清区).
Jining (济宁市): Rencheng (任城区).
Zibo (淄博市): Linzi (临淄区), Boshan (博山区), Zhoucun (周村区), Zhangdian (张店区), Zichuan (淄川区).
Binzhou (滨州市): Bincheng (滨城区).
Weifang (潍坊市): Fangzi (坊子区), Kuiwen (奎文区), Hanting (寒亭区), Shouguang (寿光区), Weicheng (潍城区).
Yantai (烟台市): Zhaoyuan (招远市), Muping (牟平区), Fushan (福山区), Zhifu (芝罘区), Laishan (莱山区), Laizhou (莱州市), Penglai (蓬莱市).
Qingdao (青岛市): Jimo (即墨市), Chengyang (城阳区), Laoshan (崂山区), Shibei (市北区), Shinan (市南区), Pingdu (平度市), Licang (李沧区), Jiaozhou (胶州市), Laixi (莱西市), Huangdao (黄岛区).
B. JAPCP-covered provincial boundaries
Liaocheng (聊城市): Dongchangfu (东昌府区).
Dezhou (德州市): Decheng (德城区).
Heze (菏泽市): Mudan (牡丹区).
C. JAPCP-uncovered boundaries
Linyi (临沂市): Hedong (河东区), Luozhuang (罗庄区).
Zaozhaung (枣庄市): Taierzhuang (台儿庄区), Yicheng (峄城区), Xuecheng (薛城区).

Notes: This table shows the classification of boundaries based on county standards. Only cities and counties in Shandong Province are listed. Each line follows this format "city: county1, county2, …." Taking the fourth row of Panel A as an example, Lanshan (county) of Linyi (city) is regarded as part of a non-boundary area. The corresponding Chinese names are marked in parentheses.

Table A.5
Using samples after PSM to reestimate the Equation (20).

	Logarithm of AQI		
	Radius matching	Kernel matching	One-to-one matching
	(1)	(2)	(3)
A. JAPCP-covered provincial boundaries			
Boundary × Post	-0.114***	-0.110***	-0.114***
	(0.018)	(0.021)	(0.018)
Adj. R^2	0.931	0.931	0.931
Observations	2773	2666	2773
B. JAPCP-uncovered provincial boundaries			
Boundary × Post	0.069***	0.076***	0.069***
	(0.025)	(0.029)	(0.025)
Adj. R^2	0.928	0.929	0.928
Observations	2412	2385	2412
Control variables	Yes	Yes	Yes
Month FE	Yes	Yes	Yes
Station FE	Yes	Yes	Yes
Wind direction × Month FE	Yes	Yes	Yes

Notes: This table uses the PSM-adjusted sample to re-estimate Equation (20). Columns (1)–(3) use 1% radius matching, kernel matching (Epanechnikov kernel), and one-to-one matching, respectively. In Panel A, we set $Post_t = 1$ after March 2017, and in Panel B, we set $Post_t = 1$ after October 2017. Robust standard errors clustered at the station level are present in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

Table A.6
Use the logarithm of the concentration of different atmospheric pollutants to re-estimate Equation (20).

	$PM_{2.5}$	PM_{10}	CO	NO_2
	(1)	(2)	(3)	(4)
A. JAPCP-covered provincial boundaries				
Boundary × Post	-0.084***	-0.103**	-0.236***	-0.037
	(0.027)	(0.018)	(0.040)	(0.037)
Adj. R^2	0.896	0.908	0.795	0.814
Observation	4703	4704	4696	4705
B. JAPCP-uncovered provincial boundaries				
Boundary × Post	0.053**	0.060**	0.022	0.115**
	(0.025)	(0.028)	(0.075)	(0.052)
Adj. R^2	0.894	0.904	0.782	0.808
Observations	4503	4504	4496	4505
Control variables	Yes	Yes	Yes	Yes
Month fixed effect	Yes	Yes	Yes	Yes
Station fixed effect	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes

Notes: This table uses the logarithms of the concentrations of $PM_{2.5}$, PM_{10}, CO, and NO_2 to re-estimate Equation (20). In Panel A, we set $Post_t = 1$ after March 2017, and in Panel B, we set $Post_t = 1$ after October 2017. Robust standard errors clustered at the station level are present in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Table A.7
Falsification test in Shanxi, Henan, and Hebei Province.

	Logarithm of AQI		
	Shanxi Province	Henan Province	Hebei Province
	(1)	(2)	(3)
Boundary × Post	0.039	0.024	0.007
	(0.029)	(0.015)	(0.047)
Control variables	Yes	Yes	Yes
Month fixed effect	Yes	Yes	Yes
Station fixed effect	Yes	Yes	Yes
Adj. R^2	0.772	0.902	0.862
Observations	3373	4466	2625

Notes: This table investigates the changes in atmospheric pollution at the boundaries of Shanxi, Henan, and Hebei Provinces after implementing the JAPCP. The samples contain only the non-boundary areas and boundaries between JAPCP provinces. Robust standard errors clustered at the station level are shown in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Table A.8
Excluding the "Beijing effect."

	JAPCP-covered boundary			JAPCP-uncovered boundary		
	(1)	(2)	(3)	(4)	(5)	(6)
Boundary × Post	-0.096***	-0.084***	-0.083***	0.053***	0.041**	0.042**
	(0.145)	(0.016)	(0.016)	(0.018)	(0.020)	(0.019)
Distance × Post		0.090**			0.060*	
		(0.035)			(0.033)	
Distance (ln) × Post			0.546**			0.501**
			(0.210)			(0.229)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Month fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Station fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction × Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.918	0.918	0.918	0.915	0.915	0.915
Observations	4701	4701	4701	4499	4499	4499

Notes: "Distance" ("Distance (ln)") represents (the logarithm of) the distance of the station from Beijing. Robust standard errors clustered at the station level are shown in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

Table A.9
Correlation between the number of enterprises in different industries and AQI.

	Logarithm of AQI						
	Key regulated industries				Other industries		
	C26	C28	C29	C32	C25	C30	C31
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Number of enterprises	0.297***	0.034	0.213***	0.166***	0.128***	-0.050	-0.026
	(0.056)	(0.037)	(0.032)	(0.048)	(0.028)	(0.138)	(0.023)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.943	0.944	0.944	0.942	0.942	0.940	0.940
Observations	648	586	648	648	648	648	648

Notes: This table relates the number of enterprises in different industries to AQI. To eliminate confounding factors, we use only stations located at provincial boundaries. Robust standard errors clustered at the station level are shown in parentheses.
$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.

Table A.10
The change in the distribution of polluting enterprises at the boundaries of Jiangsu Province.

	Key regulated industries			
	C26	C28	C29	C32
	(1)	(2)	(3)	(4)
Boundary × Post	-0.038	-0.132	0.123**	-0.050
	(0.033)	(0.129)	(0.049)	(0.048)
Adj. R^2	0.932	0.902	0.844	0.937
Observation	1728	1728	1728	1728
Controls	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes

Notes: This table uses samples from Jiangsu Province to illustrate that the changes in policy-uncovered boundaries in Shandong Province were not caused by natural factors, such as wind direction changes. The dependent variable in each column is the logarithm of the number of enterprises in each industry. We refer to C26, C28, C29, and C32 as key regulated industries. See Section 6.1 for details. Robust standard errors clustered at the station level are present in parentheses.
***$p < 0.01$; **$p < 0.05$; *$p < 0.1$.

Table A.11
Re-estimating the change in polluting enterprises in different industries using the adjusted sample.

	Key regulated industries				Other industries		
	C26	C28	C29	C32	C25	C30	C31
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
A. JAPCP-covered provincial boundaries							
Boundary × Post	-0.142***	-0.462***	-0.197***	-0.344***	-0.309***	-0.077*	-0.144
	(0.047)	(0.155)	(0.063)	(0.069)	(0.081)	(0.044)	(0.213)
Adj. R^2	0.906	0.700	0.907	0.919	0.925	0.906	0.854
Observations	1635	1635	1635	1635	1635	1635	1635
B. JAPCP-uncovered provincial boundaries							
Boundary × Post	0.045	-0.081***	0.056*	0.183***	-0.054*	0.081***	-0.035
	(0.032)	(0.030)	(0.30)	(0.034)	(0.027)	(0.022)	(0.177)
Adj. R^2	0.978	0.939	0.964	0.954	0.988	0.959	0.904
Observations	3230	3238	3230	3230	3230	3230	3230
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SUE chi-sq	7.76	6.11	9.85	47.21	9.92	9.16	0.47

Notes: This table uses the adjusted samples to reestimate the change in polluting enterprises in different industries. The stations not covered by the JAPCP are deleted in Panel A, and the stations covered by the JAPCP are deleted in Panel B. In each column, the seemingly unrelated estimation is used to test whether the estimated coefficients in Panel A and B are statistically equal, and the last row reports the chi-sq. Robust standard errors clustered at the station level are shown in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

Table A.12
Re-estimating the change in environmental regulation intensities using the adjusted sample.

	Frequency			Frequency per 10000 words		
	"huanjing"	"huanbao"	"wuran"	"huanjing"	"huanbao"	"wuran"
	(1)	(2)	(3)	(4)	(5)	(6)
A. JAPCP-covered provincial boundaries						
Boundary × Post	3.405	0.052	-0.630	2.828*	-0.128	-0.230
	(2.474)	(0.420)	(0.996)	(1.648)	(0.321)	(0.710)
Adj R^2	0.677	0.706	0.376	0.447	0.744	0.322
Observations	1665	1665	1665	1665	1665	1665
B. JAPCP-uncovered provincial boundaries						
Boundary × Post	-5.212***	-2.759***	-2.498**	-2.054***	-1.566***	-1.543**
	(0.830)	(0.402)	(0.940)	(0.353)	(0.251)	(0.491)
Adj R^2	0.706	0.655	0.485	0.566	0.641	0.514
Observations	3279	3279	3279	3279	3279	3279
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Wind direction	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table uses the adjusted samples to reestimate the change in environmental regulation intensities. The stations not covered by the JAPCP are deleted in Panel A, and the stations covered by the JAPCP are deleted in Panel B. Robust standard errors clustered at the station level are shown in parentheses.
***p < 0.01; **p < 0.05; *p < 0.1.

Appendix B: Model extension

In the baseline model, the marginal effects of economic output and pollution on the objective function of local governments are assumed constant, facilitating the model's solution. In this appendix, we extend the model to consider the increasing marginal disutility of atmospheric pollution.

As depicted in Fig. A.2, for the sake of simplicity, we do not maintain the linear model setting but instead simplify each province into two boundary points and one central point. For Province B, the local government maximizes its objective function by determining the number of polluting enterprises at three locations $x = 2$, $x = 3$, and $x = 4$, denoted as $I_{2,B}$, $I_{3,B}$, and $I_{4,B}$, respectively (in the subscript, the number represents x and the letter represents the province).

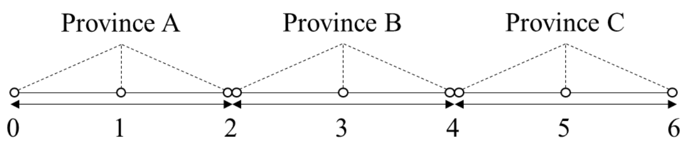

Fig. A.2. Set-up before the JAPCP in the extended model.

To map the incremental negative effects of atmospheric pollution, we assume that they manifest in a secondary form in the target functions of local governments:

$$U = m \times \text{Economic Output} - n \times \text{Pollution}^2$$

The enterprise's investment costs and pollution spillover effects are the same as those in the benchmark model. Thus, the optimization problem for Province B is:

$$\max_{\{I_{2,B}, I_{3,B}, I_{4,B}\}} U_B = m \sum_{i=2}^{4} A_{i,B} I_{i,B}^{\alpha} - n \left(\sum_{i=2}^{4} B_{i,B} I_{i,B}^{\alpha} + \text{Sp}_B \right)^2 - (1+r)C \sum_{i=2}^{4} I_{i,B} \quad \text{(A1)}$$

where Sp_B represents the pollution spillover effect suffered by Province B, including pollution spillover from various locations within Province B and neighboring provinces. This setting enables local governments to observe each other's enterprise distribution decisions and achieve equilibrium through dynamic adjustments. Specifically,

$$\begin{aligned} \text{Sp}_B = & B_{2,B}\left(I_{0,A}^{\alpha}\delta^2 + I_{1,A}^{\alpha}\delta + I_{2,A}^{\alpha} + I_{3,B}^{\alpha}\delta + I_{4,B}^{\alpha}\delta^2 + I_{4,C}^{\alpha}\delta^2 + I_{5,C}^{\alpha}\delta^3 + I_{6,C}^{\alpha}\delta^4\right) \\ & + B_{3,B}\left(I_{0,A}^{\alpha}\delta^3 + I_{1,A}^{\alpha}\delta^2 + I_{2,A}^{\alpha}\delta + I_{2,B}^{\alpha}\delta + I_{4,B}^{\alpha}\delta + I_{4,C}^{\alpha}\delta + I_{5,C}^{\alpha}\delta^2 + I_{6,C}^{\alpha}\delta^3\right) \\ & + B_{4,B}\left(I_{0,A}^{\alpha}\delta^4 + I_{1,A}^{\alpha}\delta^3 + I_{2,A}^{\alpha}\delta^2 + I_{2,B}^{\alpha}\delta^2 + I_{3,B}^{\alpha}\delta + I_{4,C}^{\alpha} + I_{5,C}^{\alpha}\delta + I_{6,C}^{\alpha}\delta^2\right) \end{aligned} \quad \text{(A2)}$$

We define $\Omega_B = \sum_{i=2}^{4} B_{i,B} I_{i,B}^{\alpha} + \text{Sp}_B$, and three first-order conditions can be obtained as follows:

$$\frac{\partial U_B}{\partial I_{2,B}} = m A_{2,B} \alpha I_{2,B}^{\alpha-1} - 2n\Omega_B \left(B_{2,B} + B_{3,B}\delta + B_{4,B}\delta^2\right) \alpha I_{2,B}^{\alpha-1} - (1+r)C = 0 \quad \text{(A3)}$$

$$\frac{\partial U_B}{\partial I_{3,B}} = m A_{3,B} \alpha I_{3,B}^{\alpha-1} - 2n\Omega_B \left(B_{2,B}\delta + B_{3,B} + B_{4,B}\delta\right) \alpha I_{3,B}^{\alpha-1} - (1+r)C = 0 \quad \text{(A4)}$$

$$\frac{\partial U_B}{\partial I_{4,B}} = m A_{4,B} \alpha I_{4,B}^{\alpha-1} - 2n\Omega_B \left(B_{2,B}\delta^2 + B_{3,B}\delta + B_{4,B}\right) \alpha I_{4,B}^{\alpha-1} - (1+r)C = 0 \quad \text{(A5)}$$

Similarly, we can write the optimization problems for Provinces A and C, and then obtain three first-order conditions for each province. The equilibrium number of polluting enterprises in each place can be obtained by solving the nonlinear simultaneous equations for the nine first-order conditions.

We calculate the numerical solution of the simultaneous equations using the values of the parameters described in Section 3.3. Table A.13 presents the relative numbers of polluting enterprises and atmospheric pollution in the boundary (i.e., at $x = 2$ or $x = 4$) and non-boundary area (i.e., at $x = 3$) for various parameter values. The number of polluting enterprises and level of pollution in the boundary area are greater than those in the non-boundary area for a range of parameter values, indicating that the pollution boundary effect remains in the extended model.

Table A.13
The relative number of polluting enterprises and atmospheric pollution at boundaries before the JAPCP.

Parameters		Relative number of polluting enterprises at boundaries	Relative atmospheric pollution at boundaries
m	δ		
0.9	0.10	1.0824	1.5729
1.0	0.10	1.0869	1.5735
1.1	0.10	1.0909	1.5741
1.2	0.10	1.0943	1.5746
1.0	0.08	1.1989	1.6489
1.0	0.15	1.0153	1.4335

Notes: This table shows the ratio of the number of polluting enterprises and atmospheric pollution at boundaries to those in non-boundary areas before the JAPCP under different parameter values in the extended model.

After the implementation of JAPCP, Provinces B and C form an environmental coalition, as shown in Fig. A.3. The spillover pollution caused by Province B on Province C is included in the objective function of the government of Province B:

$$\max U_B' = m\sum_{i=2}^{4} A_{i,B} I_{i,B}^{\alpha} - n\left(\sum_{i=2}^{4} B_{i,B} I_{i,B}^{\alpha} + \mathrm{Sp}_B + \mathrm{Sp}_{BC}\right)^2 - (1+r)C\sum_{i=2}^{4} I_{i,B} \qquad \text{(A6)}$$

where the term Sp_{BC} represents the spillover pollution from province B to province C; that is,

$$\begin{aligned} \mathrm{Sp}_{BC} = {} & B_{4,C}\left(I_{2,B}^{\alpha}\delta^2 + I_{3,B}^{\alpha}\delta + I_{4,B}^{\alpha}\right) + B_{5,C}\left(I_{2,B}^{\alpha}\delta^3 + I_{3,B}^{\alpha}\delta^2 + I_{4,B}^{\alpha}\delta\right) \\ & + B_{6,C}\left(I_{2,B}^{\alpha}\delta^4 + I_{3,B}^{\alpha}\delta^3 + I_{4,B}^{\alpha}\delta^2\right) \end{aligned} \qquad \text{(A7)}$$

The objective function of Province C is modified similarly, whereas that of Province A remains the same. Subsequently, the change in the pollution boundary effect after JAPCP implementation is calculated by solving new nonlinear simultaneous equations for nine first-order conditions.

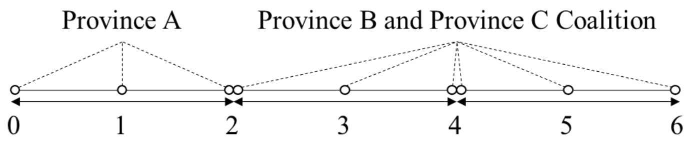

Fig. A.3. Set-up after the JAPCP in the extended model.

Table A.14 presents the number of polluting enterprises and the pollution level in the two boundaries of Province B compared to the non-boundary areas after the implementation of the JAPCP. Comparing Table A.13 with Table A.14, the pollution boundary effect at the policy-uncovered boundary rises while that at the policy-covered boundary declines, which is consistent with the theoretical hypothesis in the main text.

Table A.14

The relative number of polluting enterprises and atmospheric pollution at boundaries after the JAPCP.

Parameters		Number of polluting enterprises at boundaries		Atmospheric pollution at boundaries	
m	δ	Policy-uncovered	Policy-covered	Policy-uncovered	Policy-covered
0.9	0.10	1.0656	0.1444	1.5907	1.4217
1.0	0.10	1.0676	0.1428	1.5914	1.4010
1.1	0.10	1.0696	0.1413	1.5922	1.4293
1.2	0.10	1.0718	0.1397	1.5930	1.4188
1.0	0.08	1.0567	0.1109	1.6530	1.4553
1.0	0.15	1.0900	0.1083	1.4687	1.3086

Notes: This table shows the ratio of the number of polluting enterprises and atmospheric pollution at different boundaries to those in non-boundary areas after the JAPCP implementation under various parameter values in the extended model.