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Pressure, Performance, and Pollution: How Performance Gaps Shape Air-Quality Governance in China's Pearl River Delta

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Abstract: China's environmental governance relies on quantified league tables, but how different performance gaps motivate local action remains unclear. Using a balanced monthly panel covering nine Pearl River Delta cities from January 2019 to December 2024 (648 city-months), we distinguish historical (vs. a city's own prior month) and social (vs. peer mean) gaps, each split into positive and negative. Fixed-effects regressions show asymmetric responses. After a positive historical gap, the next-month rank worsens (winner's complacency); after a negative historical gap, the rank improves, but the gain fades within one to two months. Positive social gaps are followed by further improvements, whereas negative social gaps do not trigger the expected catch-up. Lag tests confirm dissipation within two months, consistent with short-lived "political blue-sky" effects. Moderation analysis suggests that higher environmental spending amplifies responses to historical gaps, while a larger secondary-industry share strengthens responses to social gaps. Designing incentives that combine sustained fiscal commitment with differentiated industrial policies may convert short-term ranking pressure into durable air-quality gains.

Keywords: performance gap; pressure-style governance; environmental policy implementation; Pearl River Delta

Introduction

China is a significant engine of global growth and trade, yet rapid urbanization and industrialization have laid bare a persistent neglect of air quality and ecological protection. In response, Beijing has tightened environmental policy, pairing top-down administrative commands with strong political incentives for local officials. By binding cadre promotion to measurable ecological targets, these China-style performance incentives seek to protect natural resources and generate broader regional gains.

China's post-reform success is widely traced to its distinctive administrative architecture[20]. In the five-tier hierarchy, central targets cascade downward and are enforced through quantified evaluations and incentive–sanction schemes—a governance mode scholars term the "pressure-style system"[36]. Top-down commands anchor this system[44], while upward accountability, scorecard management, and inter-jurisdictional tournaments jointly shape the implementation of environmental policy[50, 31, 2].

Upward accountability channels political incentives to city leaders, forcing them to prioritize environmental goals; quantitative scorecards translate those goals into complex indicators; and a "tournament" design spreads peer pressure horizontally, even prompting performance imitation so that no locality falls behind [39]. Empirical work confirms these levers: stricter targets produced larger PM-reduction gains in 2013-2017[13], while promotion-based incentives lowered pollution only to rebound after evaluations, revealing a strong "assessment-cycle" effect[45]. Therefore, choosing an appropriate quantitative metric is critical for capturing how China's pressure-style system steers environmental policy implementation.

As the centerpiece of China's bid to build a world-class bay area, the Guangdong–Hong Kong–Macao Greater Bay Area (GBA) is the country's most open and economically dynamic region. Its engine is the Pearl River Delta (PRD) cluster—Shenzhen, Guangzhou, Zhuhai, Foshan, Dongguan, Zhaoqing, Jiangmen, Huizhou, and Zhongshan—an advanced-manufacturing and modern-services hub that anchors China's integration into global markets. Covering 55,300 km² (one-third of Guangdong, 0.57 % of China's land), the PRD housed 64.5 million residents and produced RMB 8.68 trillion in GDP in 2019, or 80.7 % of provincial output, making it the primary growth driver of the GBA.

The PRD cities are now under intensive ecological remediation mandates. In June 2018, the CPC Central Committee and the State Council issued the "Opinion on Strengthening Ecological Protection and Winning the Battle against Pollution," cascading responsibility to provincial and municipal party chiefs and requiring localized implementation plans. During his October 2020 inspection tour of

Guangdong, President Xi underscored high-quality development for the Greater Bay Area; by year-end, the Ministry of Ecology and Environment had completed an integrated GBA environmental blueprint and ordered each jurisdiction to leverage its comparative advantages while meeting shared targets. To operationalize these directives, Guangdong Province released the "Three Lines and One List" zoning scheme in January 2021, transmitting top-down pressure and obliging every city to draft its control plan. The provincial data portal now publishes monthly air-quality figures and league tables, making rank comparisons a core metric for evaluating the environmental performance of city leaders.

In recent years, how organizational performance shapes managerial behavior has become a core concern in public administration and organization theory. "Performance gaps"—the distance between actual outputs and established targets—drive risk attitudes and policy adjustments[51]. These gaps are split into historical gaps (versus past performance) and social gaps (versus peer averages). This framework explains why local governments may tighten or relax pollution controls in environmental governance. For example, EU municipalities often under-comply when higher-level pressure is weak or business lobbying is intense[17], whereas in England, embedding sustainability values and collaborative cultures can spur green governance despite institutional fragmentation [8]. Crucially, when environmental indicators enter official evaluations alongside public disclosure, high-intensity targets under China's pressure-style system compel greener outcomes, especially where transparency and civic engagement are high [11, 53]. Yet China's current assessment still lacks systematic quantification of these gaps, limiting precision in policy appraisal. Focusing on nine Pearl River Delta cities, we construct monthly historical and social gap measures from air-quality rankings to assess how China's pressure-style incentives produce "catch-up" or "complacency" effects. This dynamic gap–performance analysis not only delineates the boundaries of China's incentive system but also offers policy lessons for other developing countries seeking to balance economic growth with environmental protection.

We analyze national, provincial, and municipal socioeconomic indicators alongside spatial vector data, focusing on the nine Pearl River Delta cities—Shenzhen, Guangzhou, Zhuhai, Foshan, Dongguan, Zhaoqing, Jiangmen, Huizhou, and Zhongshan. We run regressions on a balanced monthly panel for the nine Pearl River Delta cities from 2019 to 2024. The baseline specification includes city fixed effects and year–month fixed effects, which control for time-invariant city traits and contemporaneous common shocks while retaining within-city monthly variation for identification. To assess persistence, we add 1–4 lags of the dependent variable. We then estimate moderation by interacting environmental spending × historical/social performance gaps and industrial structure × social performance gaps. Standard errors are clustered by city. For robustness, we implement a leave-one-city jackknife and

alternative dependent-variable checks, confirming that the main results hold across error structures, samples, and measurement choices.

This study contributes to understanding China's pressure-style governance and environmental policy implementation in several key ways. First, leveraging high-frequency air-quality ranking data to operationalize positive and negative historical and social performance gaps uncovers asymmetric local responses to different ranking signals. Second, integrating fiscal and industrial structure as moderating factors demonstrates that the motivating effect of performance gaps is contingent on resource endowments and sectoral composition. Third, its dynamic fixed-effects design with lagged dependent variables and leave-one-city jackknife robustness checks advances methodological standards for evaluating short-lived policy incentives.

The remainder of this paper is structured as follows. Section "Literature Review" synthesizes the evolution of China's pressure‐style governance, introduces the performance‐gap framework—distinguishing positive and negative historical and social gaps—and reviews empirical studies on environmental policy incentives. Section "Research Design" details our 2019–2024 monthly panel for nine Pearl River Delta cities, defines the four gap measures and control variables, and lays out the two‐way fixed‐effects, lagged‐variable, and interaction models used to test our hypotheses. Section "Results and Discussion" presents baseline OLS, fixed‐ and random‐effects estimates, examines the short‐lived dynamics of gap‐induced incentives, analyzes how environmental spending and industrial structure moderate these effects, and validates findings through jackknife and alternative‐variable robustness checks. Finally, the Section "Conclusion" distills the policy implications, arguing that sustained fiscal commitment, differentiated industrial strategies, and transparent ranking mechanisms are essential to translate brief ranking pressures into lasting air‐quality improvements.

Literature Review

Political system, pressure-style system, and political incentives

China's political system exhibits a fundamental tension. On the one hand, central leaders have recognized the importance of environmental regulation in improving ecological outcomes. On the other hand, the political momentum generated at the national level often weakens as policy goals are transmitted through multiple layers of state structure[22,23,32]. This institutional fragmentation has led scholars to characterize China's environmental governance as a form of "fragmented authoritarianism"[34] . When environmental policies are delegated to lower levels, conflicting interests arise—particularly between officials responsible for economic growth and those tasked with environmental protection—making practical cooperation difficult to sustain.

To rectify systemic weaknesses, Beijing has tightened oversight of local governments through technocratic procedures, dense, challenging targets, composite evaluations, and cross-level accountability. This rigid "pressure system" strengthens upper-level mobilization, standardizes grassroots governance, and boosts policy execution [20]. Empirical work shows that such complex instruments can yield environmental gains: short-term political tools adjust conflicts between green goals and vested interests incrementally [41]. The River-Chief scheme—China's flagship pressure mechanism—links upward accountability, target metrics, and delegated duties to provide strong incentives for local compliance [43]. Quasi-experimental studies further find that performance league tables spur greater information disclosure in urban air-pollution control [27], while target setting in "dual-control zones" for acid rain and SO_2 has significantly lowered pollutant concentrations[4].

To shift local officials' incentives, Beijing has tied promotion prospects to meeting environmental and energy targets; cadres must hit these benchmarks to advance [3]. Embedding institutionalized political incentives in the appraisal system can energize local environmental action [33], and officials with closer ties to the center work harder to achieve emission-reduction goals in pursuit of promotion[21]. Critics, however, question the scheme's effectiveness. Under the pressure system, higher authorities rarely punish party secretaries for ecological failures [16], and the primacy of GDP targets often leaves local governments unwilling or unable to regulate pollution [47]. Narrow promotion criteria limited earmarked funding, and short tenures further encourage short-termism [46]. Quantified targets have also sparked data manipulation and even collusion to evade oversight [49]. Addressing these concerns remains a central task for research on China's environmental performance.

Performance Gap Theory

Performance-gap theory, first developed in the private sector, has gained prominence in the public arena with the rise of performance-based reforms. The concept compares actual outcomes with a reference point set by managers and focuses on how gaps below that benchmark shape managerial responses[14]. Cyert and March argued that absolute performance is a weak motivator; instead, the discrepancy between expectations and results spurs decision-making[5]. Meier, Favero, and Zhu introduced the framework to public administration, showing that the priorities of U.S. hospital CEOs and federal regulators can be explained by historical versus social gaps and by positive versus negative gaps[29]. Practically, the theory clarifies how purposeful managers drive performance improvement once a gap is made salient.

The framework separates performance feedback into two channels. A historical gap compares current results with an organization's own past results, while a social gap compares current results with peer performance. Both can be positive or negative, depending on whether the organization is above or below the reference point[51,52]. Managers use historical feedback to judge whether performance is improving or worsening, and they use social feedback to assess standing and reputation in the eyes of citizens, interest groups, and higher authorities. Evidence from Danish schools suggests that the same outcome can be interpreted differently when historical and social benchmarks point in different directions. In government settings, upper levels also evaluate subordinates by comparing them with similar jurisdictions, which fits the incentive logic of China's pressure-style system[18]. Studies of award-and-commendation programs in China further show that transparent ranking metrics, strong peer competition, and top-down rewards can strengthen local policy execution [26]. When performance exceeds the reference point, a positive gap signals that the organization has surpassed its expected or prior level, which can expand discretion and free up slack resources that managers can use to pursue future goals[29]. Conversely, falling short of the benchmark creates a negative performance gap; the threat of accountability pushes decision-makers into a problem-search and problem-solving mode. Building on this logic, we advance two baseline propositions: local officials respond positively when their environmental performance is compared with historical standards or peer expectations, adjusting their actions according to whether the gap is positive or negative.

H1a. When the historical performance gap is positive, local officials will improve environmental performance in the next evaluation period.
H1b. When the historical performance gap is negative, local officials will improve environmental performance in the next evaluation period.

H2a. When the social performance gap is positive, local officials will improve environmental performance in the next evaluation period.

H2b. When the social performance gap is negative, local officials will improve environmental performance in the next evaluation period.

In China's decentralized authoritarian system, the central–local incentive chain determines how long performance gaps matter and how quickly they fade. Central "tournament" evaluations can generate brief "political blue skies". Evidence from major events shows the pattern clearly. During the 2008 Beijing Olympics and the 2014 APEC summit, cities imposed stringent controls that cut $PM_{2.5}$ and PM_{10}, and visits by top leaders likewise induced short-term particulate declines—effects driven by incentives to demonstrate visible success[9,12]. Yet these gains fade quickly: post-event air quality often reverts within days, sometimes overshooting into "retaliatory pollution" once controls are relaxed[24, 37] . Some interventions have longer tails. About 60% of the Olympics-era reduction in the Air Pollution Index persisted four years later in some cities[9]. The Central Environmental Protection Inspection (CEPI) has also produced more durable declines in PM_{10} and SO_2 in certain locales, though effects are heterogeneous. Sustaining improvements depends on building public engagement and regional environmental management systems rather than relying on one-off campaigns[10].Carbon-market pilots show a similar, episodic pattern because tolerance and learning mechanisms are still immature[1]. Growth-first incentives push local cadres toward projects with instant payoffs, widening the gap between short-term action and long-term goals[34]. Over time, uneven political, administrative, and legal capacities lock regions into persistent high- and low-governance trajectories [15]. Although heavy central pressure can raise firm-level compliance, local autonomy and interest redistribution often dilute its effect, producing lasting regional disparities[42]. Leadership turnover adds volatility: new teams may launch short pollution campaigns, but frequent rotations erode policy continuity and sustained investment [7]. As a result, ranking gaps spark action in the current month but rarely carry influence over longer horizons.

H3. Environmental performance gaps affect air-quality rankings only in the month they occur.

Under China's pressure-style system, a downward historical gap—when a city's current air-quality ranking falls below its past level—creates a strong "catch-up" incentive for local officials. Whether this political impulse yields real emission cuts depends on fiscal capacity. Larger environmental outlays finance end-of-pipe control, monitoring, and technology upgrades, shorten policy lags, and thus magnify the motivational effect of historical underperformance; tight budgets dilute it. Empirical work shows that higher public spending on the environment significantly reduces regional carbon emissions—especially where budget management and fiscal transparency are stronger—and generates larger marginal returns in China's eastern provinces[40]. Yet the payoff from green spending is conditioned by institutions,

capital, and governance structure. A favorable regulatory environment or higher levels of foreign direct investment can further enhance the impact of environmental outlays[19]. Conversely, policy design, economic context, and administrative arrangements vary across regions and sectors, producing uneven results; rigorous regulations often raise environmental performance but may yield divergent economic effects [6].

H4. Greater environmental spending by a local government significantly strengthens the positive effect of historical performance gaps on its next-period air-quality ranking.

Under the horizontal “tournament” scheme, falling below the peer average in air-quality rankings pushes local officials to tighten pollution control. Yet, the force of this peer pressure hinges on the industrial structure. When secondary industry occupies a larger share of GDP, industrial emissions are the chief source of pollution and the easiest target for rapid enforcement, making the “laggard” signal more actionable and officials’ response stronger. In service-oriented cities, the marginal payoff from additional abatement is lower, so the same social gap produces weaker motivation. Therefore, Industrial structure determines the practical levers and costs of pollution control and systematically amplifies—or dampens—the motivational power of social performance gaps.

H5. A higher secondary-industry share significantly strengthens the positive effect of social performance gaps on next-period air-quality rankings.

Research Design

Data Sources

This study combines national, provincial, and municipal socioeconomic indicators with spatial vector data. Sources include the China Statistical Yearbook, the Guangdong Statistical Yearbook, provincial open-data portals, and National Economic and Social Development Bulletins. We first defined the study's focal construct—performance gaps—then selected monthly air-quality rankings for the nine Pearl River Delta cities (Shenzhen, Guangzhou, Zhuhai, Foshan, Dongguan, Zhaoqing, Jiangmen, Huizhou, and Zhongshan) as the core metric. Because the relevant environmental policy was introduced in 2018, rankings before 2019 were excluded; the final panel spans January 2019 to December 2024. Figure 1 shows the spatial distribution of these nine cities' air-quality rankings.

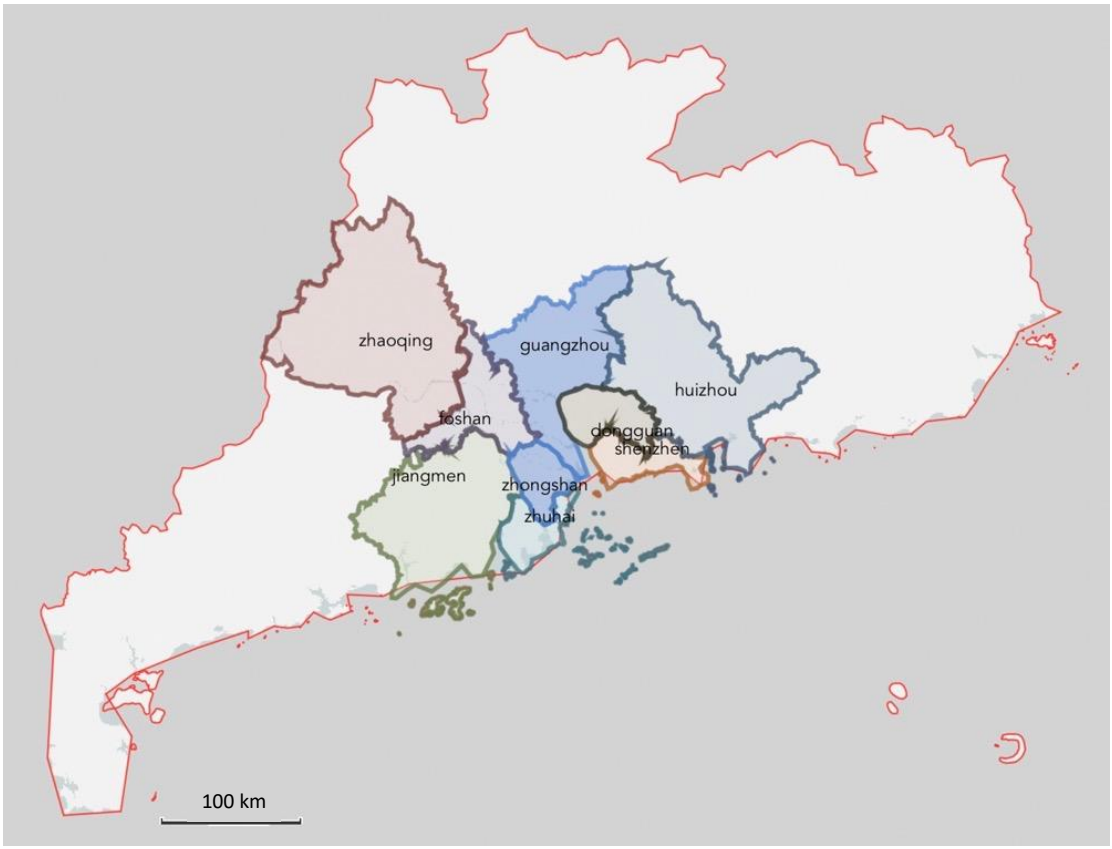


Fig.1 Nine cities ranked by ambient air quality data

Variable Settings

This study constructs eleven variables; their definitions are provided in Table 1.

Table 1 Variable Definitions and Measurement

Variable	Indicator	Definition
Environmental Air-Quality Ranking	ORIGIN	A city's position in the provincial monthly Comprehensive Air-Quality Index; lower ranks indicate better air quality.

Positive Historical Performance Gap	PHM	The improvement in a city's environmental air quality ranking from the previous month to the current month in a specific year.
Negative Historical Performance Gap	NHM	The decline in a city's environmental air quality ranking from the previous month to the current month in a specific year.
Positive Social Performance Gap	PSM	The improvement in a city's environmental air quality ranking in a specific month of a given year relative to the average ranking of comparable regions.
Negative Social Performance Gap	NSM	The decline in a city's environmental air quality ranking in a specific month of a given year relative to the average ranking of comparable regions.
GDP per capita	gdp_pc	GDP per capita is the total value of a country's finished goods and services (gross domestic product) divided by its total population (per capita).
permanent residents population	pop	Year-end resident population (10,000 persons)
Secondary Industrial Structure	ind_share	The ratio of the second industry added value to GDP (%)
Local General Public Budget Expenditure	fisc_exp	The total amount of general public budget expenditure for the year.
local environmental protection expenditure	env_spend	Energy conservation and environmental protection expenditure within the general public budget are essential indicators that reflect the government's efforts to promote sustainable development and environmental protection.
Industrial Electricity Consumption	energy_int	Total industrial electricity consumption, with higher values indicating greater energy consumption.

Dependent variable. Environmental air-quality ranking (Rank). Monthly ranks are released by the Guangdong Department of Ecology and Environment and calculated under the Technical Rules for City Air-Quality Ranking (《关于印发〈城市环境空气质量排名技术规定〉的通知》（环办〔2014〕64 号）). Although the scale is ordinal (1 = best, 21 = worst), its dense, near-interval structure allows us to treat it as continuous in the estimations. Because local enforcement often responds to the previous month's standing—creating momentum, catch-up, or rebound effects—we use the one-period lag, $Rank_{t-1}$, to reduce reverse causality and capture this dynamic inertia.

Fig.2 Monthly Air-Quality Rank Trend by City

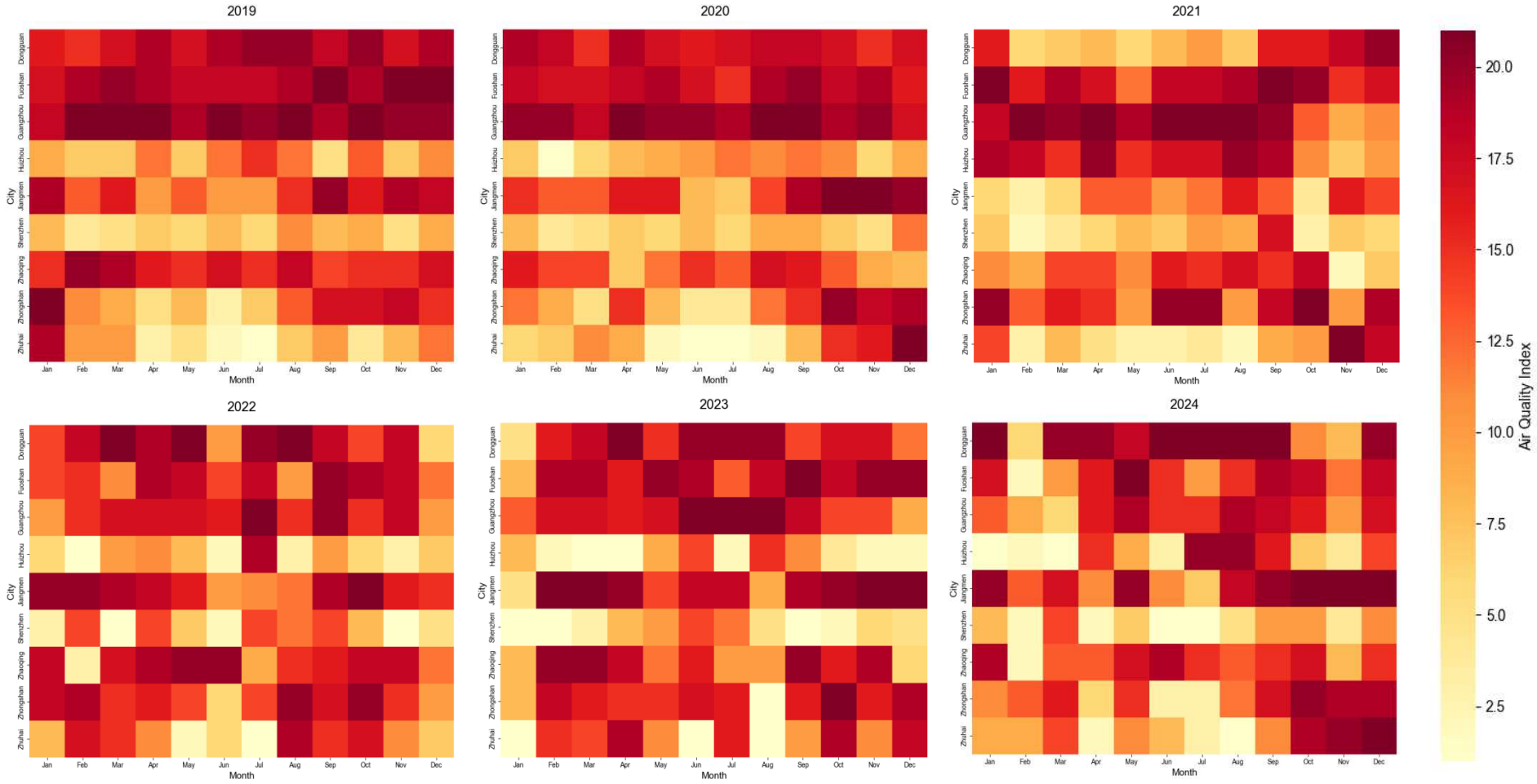


Figure 2 plots the distribution of air-quality ranks and reveals a clear core–semi-core–periphery pattern. Core. Shenzhen and Zhuhai have pursued high-end industry and service-led growth over the past decade, invested heavily in "garden city" and low-carbon infrastructure, and thus stay in the top 1-5 each month, with average ranks inside the overall top 10. Semi-core. Huizhou and Zhaoqing, which absorb spill-over industry from Guangzhou and Shenzhen (industrial share ≈45-50 percent), can leap into the 1-10 zone but—constrained by structure and fiscal capacity—often slip back below 15. Periphery. Guangzhou, Foshan, Dongguan, Jiangmen, and Zhongshan combine traditional manufacturing with transport-hub functions; high industrial energy use and vehicle emissions keep most of their monthly ranks in the 15–21 range. The pattern suggests that economic and industrial fundamentals—especially industrial share and transport scale—shape the stratification of environmental performance. Semi-core cities also respond more to ranking signals and could narrow the gap if performance assessments or fiscal support improve.

Independent variable. Performance gaps are operationalized in two dimensions.
Historical Performance Gap. For each city-month, if the air-quality rank improves relative to the previous month, the size of the improvement is recorded as a positive historical gap; otherwise, it is coded 0. If the rank worsens, the size of the decline is recorded as a negative historical gap; otherwise, it is coded 0.
Social (peer) Performance Gap. We draw on the Guangdong Survey Report on Local-Government Public-Service Satisfaction, which ranks 21 prefecture-level cities. Because eight of the nine Pearl River Delta (PRD) cities cluster within the provincial top ten, we split them into two peer groups: Tier 1 (Zhuhai, Guangzhou, Foshan, Zhongshan) and Tier 2 (Zhaoqing, Shenzhen, Dongguan, Huizhou, Jiangmen). For each month, we compute the mean air-quality rank of the relevant peer group and compare each city to that benchmark. An improvement relative to the peer mean is coded as a positive social gap (size of the improvement); otherwise, 0. A decline relative to the peer mean is coded as a negative social gap (size of the decline); otherwise, 0.

Control variables. Six covariates are included to net out non-core influences on air-quality rankings. GDP per capita (10,000 yuan/person) proxies for development level and absorptive capacity. Resident population (10,000 persons, year-end) captures emission pressure and governance difficulty tied to density. Industrial share (secondary value added/GDP, %) gauges the degree of industrialization, with higher ratios indicating a larger potential pollution base. General budget expenditure (billion yuan) represents fiscal resources and thus the capacity to fund abatement. Environmental spending (billion yuan) measures annual energy conservation and environmental protection outlays, signaling proactive commitment. Energy intensity (kWh of industrial electricity use) reflects pollution load per unit of output—the higher the consumption, the heavier the potential emissions.

The descriptive statistics are presented in Table 2. The study employs a balanced monthly panel of nine Pearl River Delta cities from January 2019 to December 2024 (72 months × 9 cities = 648 observations). Because each performance-gap variable relies on both current (t) and lagged (t–1) ranks, the first month of every year is systematically dropped, removing 54 observations (6 years × 9 cities). The adequate sample for lagged gap variables is therefore 594. Environmental expenditure data for Shenzhen, Foshan, Dongguan, and Zhaoqing in 2024 are missing, yielding 600 observations for that series, while all other macro, fiscal, and industrial controls remain complete at 648. Descriptive statistics (Table 2) show that historical and social gaps vary by more than ten ranking positions; the positive historical gap reaches a maximum of 17 places, indicating that promotion-driven incentives can produce considerable month-to-month improvements—or rebounds—in air-quality performance.

Table 2 Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ORIGIN	648	13.27	5.95	1	21
PHM	648	1.98	3.2	0	17
NHM	648	2.03	3.35	0	18
PSM	648	2.48	3.39	0	14
NSM	648	2.13	2.77	0	12
gdp_pc	648	12.5	4.21	5.39	20.57
pop	648	870.36	563.11	233.18	1,897.80
ind_share	648	45.26	9.17	25.26	58.2
fisc_exp	648	1,347.08	1,392.16	351.65	5,012.43
env_spend	600	41.94	66.59	1.58	331.63
energy_int	648	348.98	179.62	107.02	759.1

Models and Estimates

Empirical strategy. The analysis unfolds in three steps. First, we document descriptive differences between air-quality ranks and performance gaps. Second, we estimate three sets of models. Model Set 1 employs pooled OLS, two-way fixed effects, and random effects to gauge the baseline link between rank and the four gap variables. Model Set 2 regresses rank on its own one- to three-month lags to test whether officials' attention to rankings decays over time. Model Set 3 adds interaction terms for environmental spending and industrial structure to assess how fiscal resources and industrial mix moderate the gap–rank relationship; city-clustered robust standard errors are used throughout. The baseline specification is:

$$Rank_{i,t-1} = \beta_0 + \beta_1 hist_{gap_{pos_{it}}} + \beta_2 hist_{gap_{neg_{it}}} + \beta_3 soci_{gap_{pos_{it}}} + \beta_4 soci_{gap_{neg_{it}}} + control_{it} + \mu_t + \gamma_i + \varepsilon_{it}$$

（1）

$$Rank_{i,t-1} = \beta_0 + \beta_1 hist_{gap_{pos_{it}}} + \beta_2 hist_{gap_{neg_{it}}} + \beta_3 soci_{gap_{pos_{it}}} + \beta_4 soci_{gap_{neg_{it}}} + \sum_{k=1}^{3} \varnothing k Rank_{i,t-1} + control_{it} + \mu_t + \gamma_i + \varepsilon_{it}$$

（2）

$$Rank_{i,t-1} = \beta_0 + \beta_1 hist_{gap_{it}} + \beta_2 env_{spend_{it}} + \beta_3 (hist_{gap_{it}} \times env_{spend_{it}}) + control_{it} + \mu_t + \gamma_i + \varepsilon_{it}$$

（3）

$$Rank_{i,t-1} = \beta_0 + \beta_1 soci_{gap_{it}} + \beta_2 ind_{share_{it}} + \beta_3 (soci_{gap_{it}} \times ind_{share_{it}}) + control_{it} + \mu_t + \gamma_i + \varepsilon_{it}$$

（4）

In Eq. (1), i indexes cities and t denotes months. $Rank_{it}$ is the current air-quality rank, $Rank_{i,t-1}$ refers to city i's air-quality ranking in the previous month ($t - 1$).

$hist_{gap_{pos_{it}}}$ the **positive historical performance gap**—the number of rank positions city i improves from month $t - 1$ to month t. $hist_{gap_{neg_{it}}}$ the **negative historical performance gap**—the number of rank positions city i improves from month $t - 1$ to month t. $soci_{gap_{pos_{it}}}$ denotes the **positive social performance gap**—the number of rank positions city i improves from month $t - 1$ to month t. $soci_{gap_{neg_{it}}}$ denotes the **negative social performance gap**—the number of rank positions city i improves from month $t - 1$ to month t.

In Eq. (2), $\sum_{k=1}^{3} \varnothing k$ sums the coefficients on the first, second, and third lags (k=1,2,3); $\varnothing k$ is the coefficient for the k-th lag. $Rank_{i,t-k}$ is city i's air-quality ranking in period $t-k$.

In Eq. (3), the interaction term **hist_gap$_{it}$ × env_spend$_{it}$** tests whether environmental spending amplifies or weakens the motivational effect of historical gaps, while **soci_gap$_{it}$ × ind_share$_{it}$** tests whether the degree of industrialization amplifies or dampens the impact of social gaps. $control_{it}$ is the vector of control variables. μ_t denotes city fixed effects, absorbing time-invariant characteristics such as geography and local institutions. γ_i denotes month (time) fixed effects, capturing nationwide shocks such as macro policy, business cycles, or pandemics. β_0 is the intercept, and $\varepsilon_{i,t}$ is the error term.

Results and Discussion

Descriptive statistical analysis

Table 3 Baseline regression

	OLS		FE		FE-LSDV		RE	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
PHM	0.5697***	0.7091***	0.6226***	0.8038***	0.6226***	0.8038***	0.6298***	0.7854***
	(0.0493)	(0.0462)	(0.0996)	(0.0343)	(0.0996)	(0.0343)	(0.1010)	(0.0252)
NHM	-0.8567***	-0.7691***	-0.8175***	-0.7904***	-0.8175***	-0.7904***	-0.8427***	-0.8210***
	(0.0444)	(0.0406)	(0.0722)	(0.0763)	(0.0722)	(0.0763)	(0.0741)	(0.0632)
PSM	-0.8883***	-0.9035***	-0.7065***	-0.8783***	-0.7065***	-0.8783***	-0.7654***	-0.8986***
	(0.0491)	(0.0483)	(0.1302)	(0.1110)	(0.1302)	(0.1110)	(0.1232)	(0.0865)
NSM	0.5638***	0.5607***	0.5552***	0.6233***	0.5552***	0.6233***	0.5740***	0.6543***
	(0.0588)	(0.0518)	(0.0786)	(0.0702)	(0.0786)	(0.0702)	(0.0726)	(0.0612)
gdp_pc		0.0755*		-0.1674		-0.1674		0.1220
		(0.0384)		(0.1628)		(0.1628)		(0.0937)
pop		0.0065***		-0.0572		-0.0572		0.0070***
		(0.0013)		(0.0383)		(0.0383)		(0.0019)
ind_share		0.0415		-0.0876		-0.0876		0.0541
		(0.0354)		(0.2505)		(0.2505)		(0.0670)
fisc_exp		-0.0021***		0.0000		0.0000		-0.0024***
		(0.0005)		(0.0017)		(0.0017)		(0.0006)
env_spend		-0.0008		0.0034		0.0034		0.0022
		(0.0049)		(0.0085)		(0.0085)		(0.0064)
energy_int		-0.0083***		-0.0272		-0.0272		-0.0098***
		(0.0027)		(0.0184)		(0.0184)		(0.0036)
Constant	14.9025***	11.6053***	14.8423***	76.8222*	14.2813***	78.0201*	14.9429***	10.6940***
	(0.3016)	(1.6736)	(0.7767)	(38.7977)	(0.3744)	(39.7824)	(0.9767)	(3.2224)
Observations	594	550	594	550	594	550	594	550
R-squared	0.6824	0.7847	0.7219	0.8084	0.8241	0.8807		
City FE	NO	NO	YES	YES	YES	YES	NO	NO
Month FE	NO	NO	YES	YES	YES	YES	NO	NO
Number of cities			9	9			9	9

Table 3 presents the baseline estimates for the effect of performance - gap on monthly air-quality ranking. Columns 1 and 2 show the pooled OLS results, where Column 2 adds the full set of socioeconomic, fiscal, and energy controls. Columns 3 and 4 report the "within" fixed-effects estimates, including all controls. Column 5 and Column 6 replicate the fixed-effects specification with the least-squares-dummy-variable (LSDV) estimator that absorbs the complete set of city and time dummies. Columns 7 and 8 display the random-effects estimates, with Column 8 controlling for the covariates. In all specifications, we cluster standard errors at the city level (values in brackets). Significance is denoted by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.*

Table 3 presents how performance gaps affect monthly air-quality rankings. In columns 1 and 2, the pooled OLS estimates show a positive and highly significant coefficient on the positive historical gap (PHM) and a negative, significant coefficient on the negative historical gap (NHM). Exceeding one's record, therefore, induces short-lived complacency—next-month ranks rise, and air quality worsens—whereas falling behind triggers a catch-up response that quickly lowers the rank and improves air quality. Hence, H1a is not supported, while H1b is confirmed. The positive social gap (PSM) carries a negative coefficient on the peer dimension, indicating that cities already ahead of their peers continue to tighten controls. Still, the negative social gap (NSM) is positive, meaning lagging fails to spark the expected catch-up effort. Thus, H2a is supported and H2b rejected.

Columns 3 and 4 add city fixed effects and month dummies; all four gap coefficients retain their signs and significance, and the absolute values of PHM and NHM grow (0.804 and -0.790), suggesting that incentives stem mainly from within-city temporal variation rather than cross-sectional differences. Columns 5 and 6 replicate the specification with a least-squares dummy-variable estimator, yielding identical results and confirming robustness. Columns 7 and 8 treat city effects as random; the gap variables remain significant and in the same direction.

In short, officials react asymmetrically: surpassing their history breeds "winner complacency," yet they remain susceptible to staying ahead of peers; conversely, when they fall behind peers, fiscal or technological constraints can dampen the catch-up impulse, preventing the expected performance gains.

Table 4 Lagged Effects of Performance-Gap Signals on Monthly Air-Quality Ranking

	L.1	L.2	L.3	L.4
	(1)	(2)	(3)	(4)
PHM	0.8038***	0.3512***	0.2719***	0.0551
	(0.0343)	(0.0618)	(0.0716)	(0.0746)
NHM	-0.7904***	-0.1063*	-0.0269	-0.0840
	(0.0763)	(0.0511)	(0.0456)	(0.0763)
PSM	-0.8783***	-0.3202***	-0.0028	0.0609
	(0.1110)	(0.0541)	(0.0757)	(0.1243)
NSM	0.6233***	0.3765**	0.2948	-0.0118
	(0.0702)	(0.1364)	(0.1872)	(0.1498)
gdp_pc	-0.1674	0.0293	0.0827	0.1527
	(0.1628)	(0.2942)	(0.3697)	(0.4201)
pop	-0.0572	-0.0835**	-0.0965*	-0.1228**

	(0.0383)	(0.0324)	(0.0420)	(0.0479)
ind_share	-0.0876	-0.2244	-0.2529	-0.2061
	(0.2505)	(0.3456)	(0.4465)	(0.4964)
fisc_exp	0.0000	-0.0011	-0.0015	-0.0008
	(0.0017)	(0.0028)	(0.0036)	(0.0038)
env_spend	0.0034	-0.0158	-0.0292*	-0.0407**
	(0.0085)	(0.0090)	(0.0138)	(0.0137)
energy_int	-0.0272	-0.0356	-0.0362	-0.0464
	(0.0184)	(0.0229)	(0.0308)	(0.0343)
Constant	76.8222*	108.1194**	120.3754*	143.4977*
	(38.7977)	(42.8276)	(56.8131)	(63.9123)
Observations	550	500	450	400
R-squared	0.8084	0.5776	0.5535	0.5236
City FE	YES	YES	YES	YES
Month FE	YES	YES	YES	YES
Number of code	9			

Table 4 compares the baseline specification (col. 1) with fixed-effects models that lag all performance-gap variables by 2, 3, and 4 months (cols. 2–4). Robust standard errors are clustered at the city level (values in parentheses). Significance codes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4 lags each of the four performance gaps by one to four months in a city fixed-effects model. The results support H3: ranking incentives are brief and decay quickly. With a one-month lag, all four gaps remain large and significant, showing the familiar pattern of "winner complacency" and "catch-up after loss." At a two-month lag, only PHM, NHM, and PSM are still marginally significant, and their magnitudes shrink sharply. By the third month, only PHM retains significance; by the fourth, none of the gaps affect the ranking, and the model R^2 falls to 0.52. Thus, the motivational signal lasts no more than one to two months and is gone by month four—mirroring the "political blue-sky" effect, where air-quality gains during inspections or major events fade once attention shifts. Notably, the positive historical gap persists slightly longer, implying that officials can "coast" on a good ranking for another month or two. In contrast, laggard cities exhaust their catch-up momentum more rapidly because of fiscal and technical constraints.

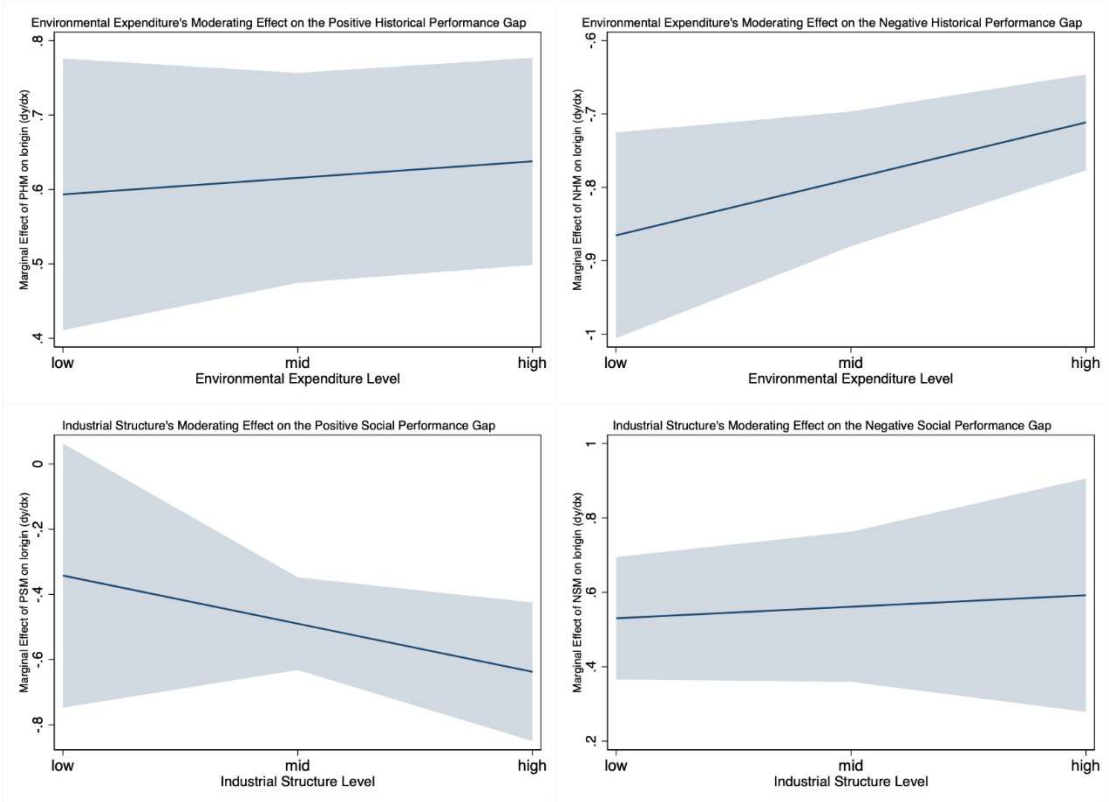


Fig. 3 Moderating Effects of Environmental Expenditure and Industrial Structure on Historical and Social Performance Gaps

Figure 3 summarizes how fiscal capacity and industrial structure moderate the four performance gaps, and the patterns are fully consistent with H4 and H5. The top row shows that a larger share of environmental expenditure magnifies the impact of positive (PHM) and negative (NHM) historical gaps on next-month air-quality ranks. Once spending rises above the mean, the pro-incentive effect of PHM strengthens. In contrast, the punitive impact of NHM softens—evidence that ample funds fuel "catch-up" efforts and help lagging cities overcome technical and enforcement constraints, confirming H4. The bottom row indicates that a higher secondary-industry share intensifies the motivational power of social gaps. For frontrunners, each 1-SD rise in industrial weight deepens the rank-lowering effect; for laggards, the same shift strengthens the rank-improving impulse. Concentrated industrial emissions give officials a clear, actionable target, making peer pressure more effective; service-oriented cities lack such quick wins, so the same gap exerts weaker pressure. These results validate H5.

Table 5 Leave-One-City Jackknife and Alternative-Specification Robustness Tests

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
PHM	0.804***	0.800***	0.798***	0.766***	0.809***	0.830***	0.801***	0.807***	0.830***	0.810***	-0.018**	0.010*	0.623***
	(0.034)	(0.027)	(0.038)	(0.028)	(0.032)	(0.053)	(0.040)	(0.034)	(0.036)	(0.037)	(0.004)	(0.003)	(0.100)
NHM	-0.790***	-0.784***	-0.781***	-0.786***	-0.778***	-0.902***	-0.782***	-0.785***	-0.796***	-0.764***	0.030*	-0.009**	-0.817***
	(0.076)	(0.066)	(0.085)	(0.082)	(0.077)	(0.042)	(0.082)	(0.072)	(0.095)	(0.077)	(0.011)	(0.002)	(0.072)

PSM	-0.878***	-0.891***	-0.855***	-0.770***	-0.867***	-0.940***	-0.878***	-0.879***	-0.988***	-0.862***	-0.141***	0.034**	-0.706***
	(0.111)	(0.102)	(0.117)	(0.105)	(0.126)	(0.151)	(0.114)	(0.111)	(0.096)	(0.110)	(0.017)	(0.007)	(0.130)
NSM	0.623***	0.634***	0.675***	0.649***	0.643***	0.598***	0.591***	0.598***	0.633***	0.605***	0.024*	-0.049***	0.555***
	(0.070)	(0.099)	(0.055)	(0.081)	(0.077)	(0.072)	(0.064)	(0.076)	(0.097)	(0.074)	(0.008)	(0.005)	(0.079)
Observations	550	484	495	484	495	484	495	484	484	495	600	600	594

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 reports the robustness checks. We conduct a leave-one-city jackknife to examine whether the main findings are driven by any single city. Keeping the time dimension and all controls unchanged, we sequentially drop one city at a time, re-estimate the model, and compare the key coefficients. Columns 1–10 show that removing any one city leaves the signs, magnitudes, and significance of PHM, NHM, PSM, and NSM essentially unchanged, indicating that the results are not city-specific. Columns 11–13 further test alternative measures and an expanded sample, and the core patterns remain stable, strengthening confidence in the robustness of our conclusions.

Conclusion

China's rapid growth has brought mounting environmental strains that threaten long-term development, making green progress and cleaner air core performance goals for the state. By embedding hard metrics and cross-level accountability into its five-tier bureaucracy, Beijing deploys the "pressure-style" system to compel local officials to treat environmental governance as a fixed, clearly scoped responsibility. This approach clarifies the direction and intensity of governmental effort and, in turn, reshapes state behavior and public welfare [28].

The Pearl River Delta (PRD) cities form the operational hub of the Guangdong–Hong Kong–Macao Greater Bay Area. They are central to China's ambition to build a world-class bay-area metropolis. Evaluating how local governments there execute environmental policy offers critical insights for enforcement across the mainland—and for jurisdictions worldwide seeking practical implementation tools. Drawing on 648 monthly observations from 2019-2024, this study treats each city's rank in the Comprehensive Air-Quality Index as its performance score, constructs four gap measures—positive/negative historical (PHM, NHM) and positive/negative social (PSM, NSM)—and estimates their motivational effects, plus interaction terms, with pooled OLS, two-way fixed-effects, and random-effects models.

Using monthly air-quality rankings for the nine Pearl River Delta cities from 2019 to 2024, this study compares how local officials respond to two performance gaps and then offers policy advice. The regressions reveal distinct incentive logics. When a city's current rank beats its historical average, officials tend to relax—next month's rank drifts upward—showing that a positive historical gap does not sustain effort. Falling below the historical benchmark triggers a short "catch-up" push, but the effect is modest, indicating that looking back alone cannot generate long-term pressure. Peer comparisons work differently and more durably. Cities already ahead of their peers tighten controls to stay in front, lowering their ranks (smaller numbers mean cleaner air). However, once a city slips behind, limited fiscal and technical resources constrain remedial action, and the rank improves only marginally. In short, officials are susceptible to "being ahead" but under-react to "being behind"; resource constraints partly neutralize the motivational power of negative social gaps.

Lag tests show that ranking incentives are short-lived. With a two-month lag, only PHM, NHM, and PSM remain weakly significant, and their coefficients shrink sharply; at three months and beyond, all effects vanish, indicating that the ranking signal sustains local action for no more than one to two months. Moderation analysis adds two nuances. First, higher environmental spending markedly amplifies the motivational power of historical gaps, underscoring the pivotal role of fiscal resources. Second, a larger secondary-industry share significantly strengthens the

effect of social gaps, confirming that industrial structure shapes both the feasibility and the payoff of inter-city “tournament” competition.

Our findings show that performance gaps spur local governments to act, but the strength of this motivation hinges on fiscal capacity and industrial structure. Incentive-compatible design should therefore acknowledge uneven development rather than rely on a single league table. Consistent with evidence that consultative institutions can transmit policy priorities into concrete enforcement[35], and that political incentives shape the depth of “green transformation” [30], promotion-relevant indicators ought to weight environmental outcomes alongside fiscal transparency, industrial upgrading, and citizen satisfaction. This aligns with work linking eco-environmental performance to cadre promotion prospects, which suggests that calibrated, relative metrics can maintain pressure without penalizing structural constraints [48]. Under such a scheme, front-runner cities merit escalating bonuses, technology-sharing subsidies, and cross-city diffusion mechanisms to lock in gains and avert “winner complacency,” while lagging cities require stricter accountability paired with earmarked funds, technical assistance, and capacity-building so the “last mile” does not stall.

Sustaining these incentives also depends on social acceptance and oversight. Evidence from Beijing’s traffic-related smog policies shows that instrument choice and public buy-in condition implementation quality[48], while research on environmental CSOs underscores the value of state–society complementarities for durable governance gains [38]. Building on these insights, the Greater Bay Area should host a unified, open platform that reports real-time air-quality data and policy progress at the city–month level, converting horizontal competition into routine transparency and enabling civil society and consultative bodies to monitor follow-through. Such infrastructure makes short-term ranking pressure more likely to translate into long-term air-quality improvements across heterogeneous local contexts.

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Declarations Section

Data availability

All data generated or analyzed during this study are included in this published article and its supplementary information file. https://doi.org/10.5281/zenodo.18439242

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Conflicts of Interest

The authors declare no conflict of interest.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

This article does not contain any studies with human participants performed by any of the authors.