Proximity, Development, and Environment: The Role of Remoteness in Shaping China's Air Pollution Patterns

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Abstract

Economic development - urbanization and industrialization - is linked to distance to provincial capitals in China. However, the intensity of air pollution regulation is not directly correlated with pollution levels. Instead, it depends on how many resources the local government can mobilize for governance. Due to the biased official data issue, our research uses remote sensing techniques to examine if the remoteness of the county affects the local pollution level. We first confirm a positive association between proximity to provincial capitals and economic development using cross-sectional data. Then we utilize near real-time, high-resolution NO2 concentration data from the Sentinel-5P satellite as a proxy for air quality, investigating whether pollution levels in more remote regions are less regulated. To control for the effects of built environments, we incorporate land use data from the Dynamic World dataset to isolate industrial activities from other living-related emissions. Our findings reveal that remote counties experience higher pollution levels due to economic and industrial activities, while significant political events like the 20th CPC National Congress and extra transportation convenience like accessibility to nearby ports have mitigation effects.

1 Introduction

Since China's economic reforms began in 1978, its urbanization and industrialization process has accelerated rapidly. For example. the urban population rose from 18% in 1978 to 60% by 2019. However, these trends remain spatially uneven, with eastern coastal regions much more urbanized than the interior provinces and industries concentrated near ports, cities, and infrastructure. However, remote towns and provinces in the West and Southwest regions face urbanization and industrialization challenges like underdeveloped economies, lower incomes, and lack of infrastructure.

Urban expansion's morphology and scale are molded by a complex interplay of driving forces, encompassing physical, socioeconomic, neighborhood, and land-use policy factors (Li et al., 2013). Urban growth is inherently spatially dependent; the developments in one area are influenced by the conditions in adjacent locations (Paez & Scott, n.d.). Theories of core-periphery and the diffusion of growth posit that development emanates from central urban hubs and gradually radiates outward to peripheral areas over time. Provincial capitals, being focal points of resources, industry, and productive capabilities, generate clusters of urbanization and industry that offer positive externalities such as knowledge spillovers, labor market pooling, and supplier or customer linkages. However, the strength of these agglomeration benefits wanes with increasing distance from these hubs.

In China, based on multiple natural and social endowments, provincial capitals house higher-order governmental, administrative, and infrastructure facilities. Proximate areas have better access to institutions steering development policy, approvals, and public investment. This enables more urban expansion and industrial growth. From the investment side, firms seek to locate near large urban markets, while urban development fills the demand for concentration of services and labor. Counties closer to provincial capitals have better market access and information flows, enabling higher growth. Fi-

nally, China's centralized system concentrates authority in provincial capitals providing a political economy aspect of analyzing local socio-economic development. Closer areas may lobby better for preferential policies, investment, and infrastructure upgrades from provincial leaders. This translates into quicker development progress.

While the concentration of political and economic resources around provincial capitals has historically driven rapid urbanization and industrialization in nearby regions, this geographic advantage has created an uneven landscape of development and regulatory capacity. Environmental regulation in China is heavily incentivized through hierarchical government accountability, where local government officials are evaluated based on various performance metrics. These metrics include economic growth, social stability, and environmental performance, with the weight of each criterion varying by political importance and proximity to provincial or national government centers. Our research reveals a paradox: while regions closer to provincial capitals generally demonstrate stronger economic performance, the relationship between proximity and environmental quality follows a more complex pattern, influenced heavily by local governance capabilities and regulatory enforcement capacity.

Extensive research has shed light on urban and economic growth in major Chinese cities like Beijing (Li et al., 2013), Shanghai (Q. Zhang et al., 2011), and Guangzhou (Ma & Xu, 2010), investigations into the spatial growth drivers for urban and industrial agglomerations at a municipal level in developing nations remain scarce. While there is research using spatial econometric model and satellite-monitored PM2.5 data for 280 cities to analyze the effects of environmental regulation on city air pollution treatment (G. Zhang et al., 2021), and explore how geographic proximity to ENGOs triggers green innovation of heavy pollution (Hu et al., 2021), few pieces of literature quantify how relative geographical proximity plays a crucial role in environmental regulation.

This study employed novel methodological approaches to overcome the limitations

of official environmental data and dived into higher granularity. Through the integration of remote sensing technology, specifically Sentinel-5P satellite data for NO2 concentrations, we provide an objective assessment of air quality patterns across varying distances from provincial capitals. This approach is complemented by the Dynamic World dataset, enabling precise differentiation between industrial and residential emission sources.

Our analysis demonstrates that remote counties face a dual challenge: they not only experience higher levels of air pollution but also struggle with inadequate regulatory enforcement due to limited governance resources. The research further examines how external factors, such as major political events like the 20th CPC National Congress and improvements in transportation infrastructure, temporarily influence pollution patterns. These findings have significant implications for environmental policy design, suggesting the need for regionally tailored approaches that account for both governance capacity constraints and local economic conditions.

2 Theoretical Sketch and Hypothesis

2.1 Geographical Proximity and Development

Previous evidence suggests that counties closer to provincial capitals are more developed economically due to a combination of resource advantages, market access, political attention, and infrastructure benefits (Lu et al., 2013). This provides a basis for further investigating how these dynamics also influence environmental regulation motivations and pollution outcomes across regions.

Therefore, we first hypothesize that counties closer to provincial capitals experience higher levels of economic development, characterized by increased urbanization, industrialization, and infrastructure investment, compared to more remote counties.

2.2 Relative Remoteness and Environmental Regulation

Proximity politics is a groundbreaking examination of the role of distance in shaping attitudes, behaviors, and understandings of the world. In China, geographic proximity, especially linked to travel time and transportation convenience, could have significant spillover effects to regional development (Jiang et al., 2016). Therefore, we could assume that proximity to provincial capitals enhances political visibility and oversight, which impacts the motivation of local governments to enforce environmental regulations. Closer proximity means greater direct monitoring by higher-level officials, a higher likelihood of provincial intervention in local policies, and increased media attention and public scrutiny, all of which lead to stronger motivations for local governments to regulate air pollution (Wang et al., 2016). Additionally, Proximity also affects resource allocation, impacting the capacity of local governments to implement and enforce environmental regulations.

So our second hypothesis is that local governments closer to provincial capitals are more likely to have stronger environmental regulation motivations due to higher political visibility and direct oversight by provincial authorities.

3 Data and Methodology

3.1 Data Sources and Manipulation

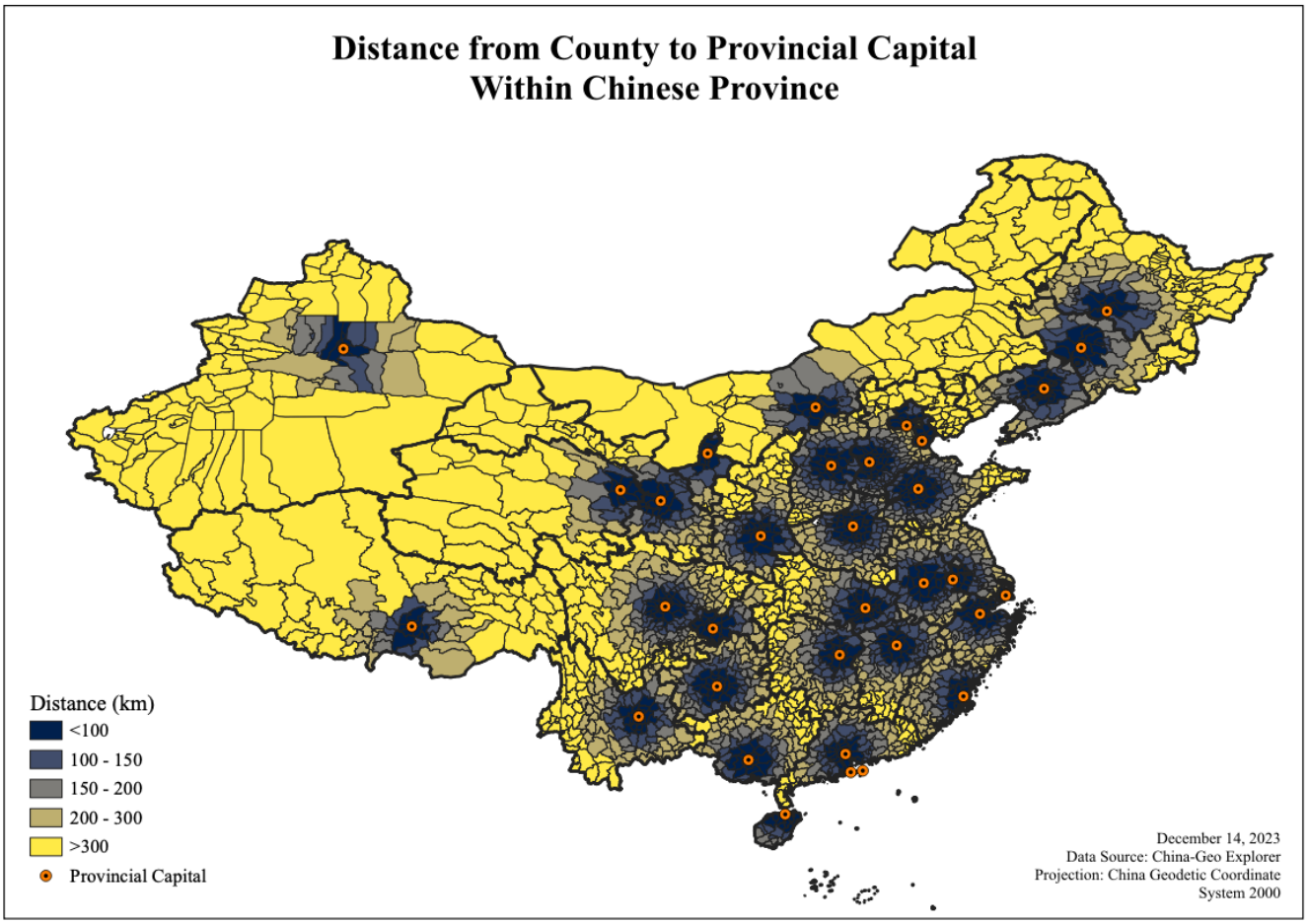
To test the relationship between proximity to provincial capitals, economic development, and air pollution, we use a combination of spatial, economic, and environmental data.

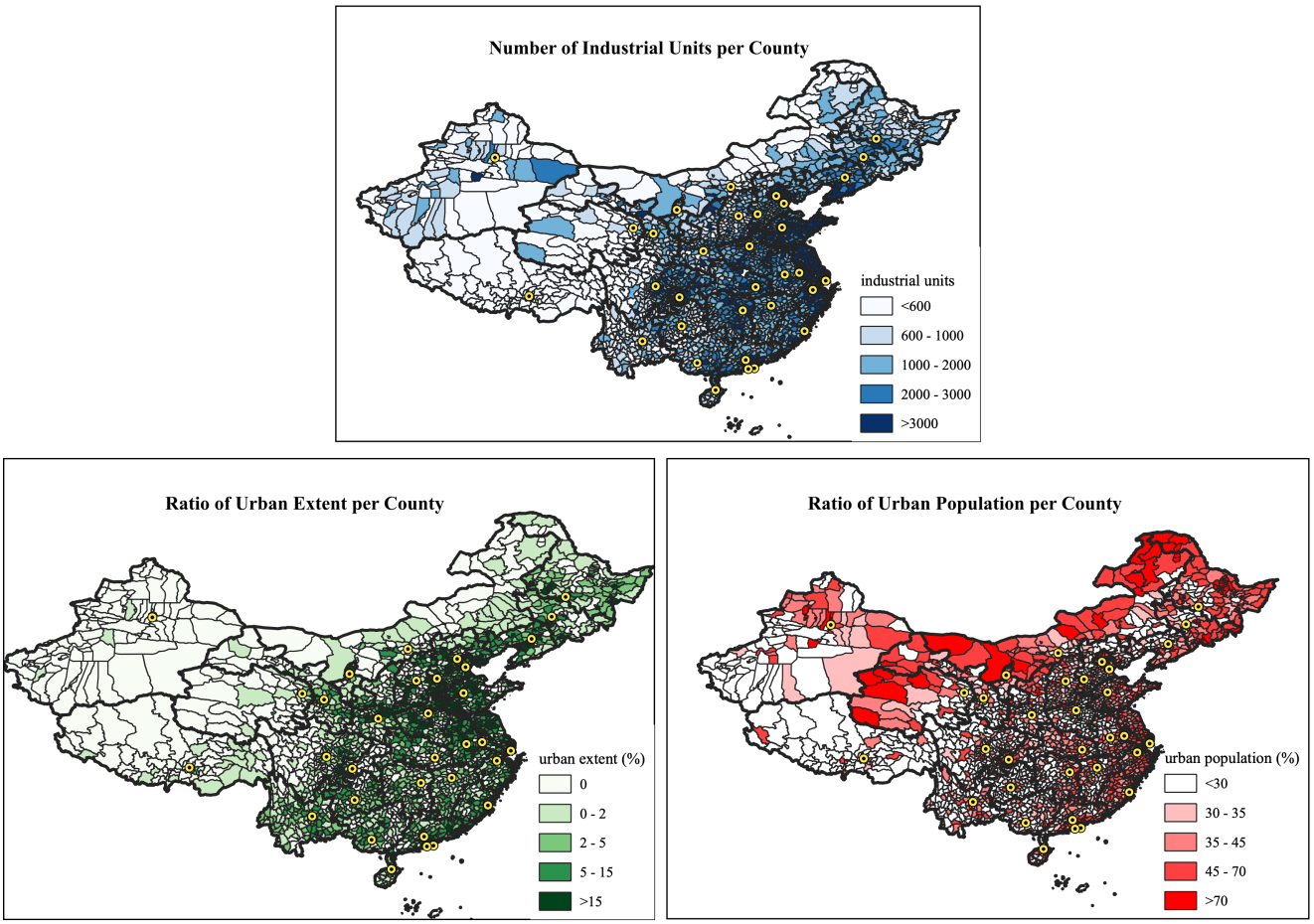
3.1.1 Proximity to Provincial Capital

Calculated as the geographic distance from the center of each county to the nearest provincial capital. This serves as an instrumental variable to capture exogenous variation in local government motivations and economic dynamics. The distance was calculated in QGIS. We first use Centroid to transform county polygons into a point layer, then we perform Join attributes by location and field value to make attribute tables with county-province GEOCODE and capital-province GEOCODE. Finally, we use the Distance matrix within a China Geodetic Coordinate System 2000 projection, to calculate distances in meters between each two county-capital and filter the rows if the county-capital pair does not belong to the same province GEOCODDE. Data was projected using the WGS 84 to China Geodetic Coordinate System 2000 transformation, which was most appropriate for the country of China. We also included a *Capital* dummy if the county is within 1 hour travel time from its provincial capital, which is calculated based on China's highway speed limit 120 km/h.

3.1.2 Economic Development Indicators

Urbanization Level: Percentage of the population living in urban areas and the urban area extent which reflects the level of urban development. The urbanization population and extent ratios in 2005 and 2010 at the county level. China Geo-Explore provided urban population in 2010. Urban extent data in 2005 can be found in the CESIN urban/rural populations and extent datasets. Finally, we got 2870 county administrations from China Geo-Explore with their population. We calculate the urban population ratio directly by using the urban population/total population. To calculate the urban extent ratio, we first loaded the urban extent raster 2005 into QGIS. We summed all urban extent points within each county using the Raster Calculator and Zonal Statistics tools.


Distance from County to Provincial Capital
Within Chinese Province
Distance (km)
<100
100 - 150
150 - 200
200 - 300
>300
Provincial Capital
December 14, 2023
Data Source: China-Geo Explorer
Projection: China Geodetic Coordinate
System 2000



Industrial Output: The share of economic output generated by the industrial sector, indicating the degree of industrialization. The industrial units in 2010 at the county level, which is directly measured by the number of industrial enterprises in each county provided by China Geo-Explore.

3.1.3 Air Pollution Data

Nitrogen Dioxide (NO2) Concentration: Using near real-time, high-resolution NO2 concentration data from the Sentinel-5P satellite as a proxy for air quality. This provides objective and consistent data across regions, mitigating the limitations of self-reported local pollution data. We used Google Earth Engine to extract the band for

the total vertical column of NO2 (ratio of the slant column density of NO2 and the total air mass factor). Then we loaded the satellite image in QGIS and utilized the Raster Calculator and Zonal Statistics tools to calculate average NO2 density by county.

3.1.4 Land Use Data

Data on land use and land cover is obtained from the Dynamic World dataset, which provides spatial information on vegetation cover, built-up areas, and water bodies. This provides a proxy of all living and industrial activities at the local level so that we can isolate the effects of regulation intensity on air pollution. We used Google Earth Engine to extract the land cover type of low and high-density buildings, roads, and urban open space. Then we loaded the raster layer in QGIS and utilized the Raster Calculator and Zonal Statistics tools to calculate the percentage of built-up area for each county.

3.1.5 Other Variables

Population: To control for other potential effects of a large amount of population on pollution levels, we got total population data by county from China Geo-Explore and merged them with our geospatial dataset.

Transportation Accessibility: Proximity to the nearby ports to account for ease of accessibility and its impact on industrial development and pollution. We calculated this proximity in the same as the provincial capital proximity. Similarly, we included a *Port* dummy if the county is within 1 hour travel time from its nearby port, which is calculated based on China's highway speed limit 120 km/h.

Significant Political Events: We include dummy variables for major political events (e.g., the 20th CPC National Congress) that could influence local government priorities and temporarily alter pollution levels.

Table 1: Summary Statistics

Variables	**Mean**	**Max**	**Min**	**SD**	**Count**
Proximity to capitals (km)	216.7	1505.8	0	185.4	16794
Urban extent (%)	0.1	1	0	0.18	16794
Urban population (%)	0.46	1	0	0.25	16794
Industrial units	2515	61853	0	3913.4	16794
NO2 Concentration (mol/m^2)	1.2e-04	6.5e-04	4.3e-05	7.1e-05	16794
Built-up area (%)	0.13	1	0	0.17	16794
Capital (=1	0.31	1	0	0.47	16794
Port (=1)	0.13	1	0	0.34	16794

3.1.6 Summary Statistics

After cleaning, merging, and combining economic, demographic, and air pollution data for 2850 counties and 5 years (2018-2023), we obtained 16794 observations, in which air pollution indicators have county-year variation, economic and demographic indicators have county variation. Table 1 shows the data summary statistics.

3.2 Empirical Methodology

We examined how proximity to provincial capitals influences the relationship between economic development and air pollution through a mediation effect. Specifically, we hypothesize that proximity to provincial capitals acts as a mediating factor that modifies the impact of economic development on pollution levels by affecting local government regulatory motivations. We employ a series of regression models that incorporate interaction terms between proximity and economic development variables, allowing us to capture how spatial and political factors shape pollution outcomes across different regions in China.

3.2.1 Economic Development Hypothesis

To confirm that proximity to provincial capitals is associated with higher economic

development, we start with a cross-sectional OLS regression analysis:

$$\text{Economic Development}_i = \alpha + \beta \times \text{Proximity to Provincial Capital}_i + \gamma \times \text{Controls}_i + \epsilon_i \tag{1}$$

where i represents each county, $\text{Proximity to Provincial Capital}_i$ is the distance from county i to the nearest provincial capital, Controls_i includes variables such as population density and infrastructure access, and ϵ_i is the error term. A negative coefficient on proximity ($\beta < 0$) would indicate that counties closer to provincial capitals exhibit higher levels of economic development.

3.2.2 Interaction between Proximity and Development on Pollution

In the second stage, we investigate how proximity to provincial capitals mediates the relationship between economic development and pollution levels. We introduce an interaction term between proximity and economic development indicators in our pollution regression model. This interaction term allows us to assess whether the effect of economic development on pollution levels varies depending on a county's distance from its provincial capital:

$$\begin{aligned}\text{Pollution Level}_{it} = \alpha &+ \theta_1 \times \text{Economic Development}_i \\ &+ \theta_2 \times \text{Proximity to Provincial Capital}_i \\ &+ \theta_3 \times (\text{Economic Development}_i \times \text{Proximity to Provincial Capital}_i) \\ &+ \lambda \times \widehat{\text{Environmental}}\ \text{Regulation}_i \\ &+ \gamma \times \text{Controls}_i + \epsilon_i\end{aligned} \tag{2}$$

where Pollution Level_i is the air pollution level in county i (measured via NO2 concen-

tration) at year t, Economic Development$_i$ includes economic variables such as urbanization level and industrial output, and Economic Development$_i$×Proximity to Provincial Capital$_i$ is the interaction term that captures the mediating effect of proximity on the relationship between economic development and pollution.

3.2.3 Instrumental Variable (IV) for Addressing Endogeneity

To address potential endogeneity issues, we employ an instrumental variable approach, using proximity to provincial capitals as an instrument for local regulatory motivations. By isolating the exogenous variation in regulation due to proximity, we can more accurately assess the causal relationship between economic development, regulatory motivation, and pollution. In the first stage, we use proximity to provincial capitals as an instrument to predict the stringency of local environmental regulation:

$$\text{Environmental Regulation}_i = \alpha + \delta \times \text{Proximity to Provincial Capital}_i + \gamma \times \text{Controls}_i + \nu_i \tag{3}$$

where Environmental Regulation$_i$ represents the regulatory strictness in county i, ν_i is the error term.

The second-stage model incorporates the predicted environmental regulation as a mediating factor in the pollution regression, alongside the economic development variables and their interaction with proximity, as represented by equation (2) where $\widehat{\text{Environmental}}$ Regulation$_i$ is the predicted value from the first stage.

3.2.4 Robustness Check

To ensure the validity of our results, we incorporate several robustness checks, including subsample regressions by region, controls for significant events (e.g., COVID-19, 20th CPC National Congress), and the effects of port accessibility. These checks help

confirm that the mediation effect of proximity on the development-pollution relationship is consistent across different regional contexts and under varying external conditions.

4 Results

The scatter plots initially corroborate our quantitative results. For development metrics, the visual representation shows a clear pattern where proximity to provincial capitals correlates with increased urban extent, population, and industrial units. In the analysis of pollution, a negative trend between proximity and NO2 levels supports the hypothesis that regions further from provincial centers experience higher pollution, likely due to weaker enforcement of environmental regulations.

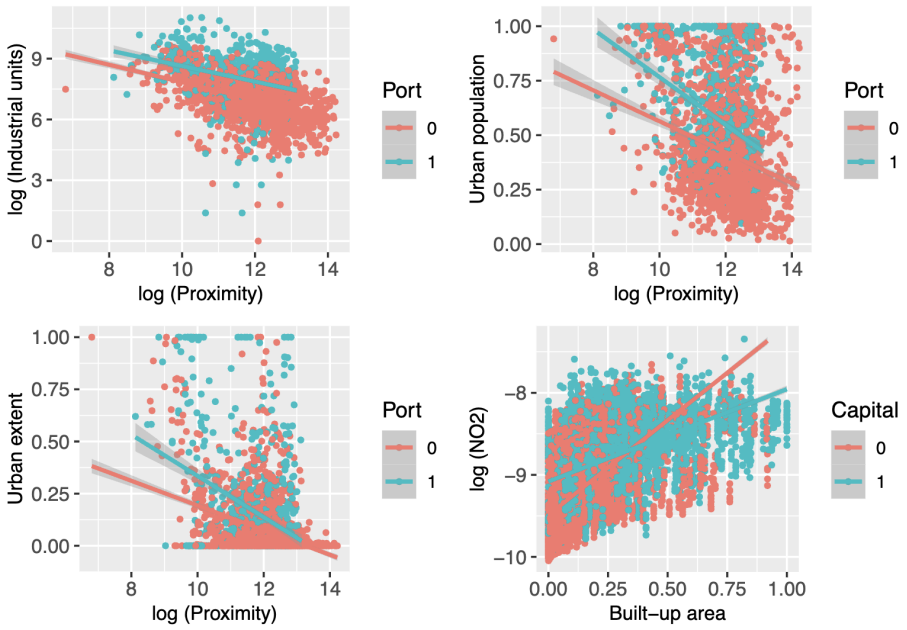


Table 2 and Table 3 represents the empirical results on the relationship between proximity to provincial capitals and regional development, as well as the subsequent impact on pollution levels. The findings align with our hypothesis that closer geospatial proximity to administrative centers enhances local development due to better access

to resources and governance. However, this dynamic also influences pollution levels, contingent upon regulatory enforcement.

4.1 Spatial Proximity and Regional Development

Table 2 illustrates the results of cross-section OLS regressions assessing the impact of proximity to provincial capitals on urban development indicators, including urban extent, population, and industrial units. The estimated coefficients indicate that closer proximity significantly fosters regional development. The coefficient for the log of proximity in the model for urban extent is -0.04 ($p < 0.01$), suggesting that counties nearer to provincial centers have a larger urban extent. The urban population model yields a more substantial coefficient of -0.16 ($p < 0.01$), reinforcing the notion that population density increases with proximity. The most pronounced effect is observed in the number of industrial units, with a coefficient of -0.38 ($p < 0.01$), indicating a dense concentration of industrial activities in areas closer to the provincial capitals.

The interaction terms between proximity and port accessibility do not show significant effects, indicating that while ports may provide logistical and economic advantages, they do not fundamentally alter the proximity-development relationship.

4.2 Development, Proximity, and Pollution

The analysis presented in Table 3 examines how urbanization, industrialization, and proximity interact to influence pollution levels, as proxied by NO2 concentrations. The fixed effect model results indicate that urban built-up areas have a positive and significant effect on pollution (β=1.16, $p < 0.01$), confirming that urban sprawl contributes to higher pollution levels. Total population also exhibits a positive relationship with pollution, with a coefficient of 0.08 ($p < 0.01$), highlighting the environmental implications of human activities. The coefficient for the log of proximity is negative and

Table 2: Effects of Proximity on Regional Development

Dependent Variables:	log (Urban Extent)	log (Urban Population)	log (Industrial Units)
	OLS (1)	OLS (2)	OLS (3)
Model:	(1)	(2)	(3)
Variables			
Constant	0.68***	1.1*	12.3***
	(0.09)	(0.56)	(0.68)
log (Proximity)	-0.04***	-0.16***	-0.38***
	(0.007)	(0.05)	(0.05)
Port	0.34	0.37	0.31
	(0.39)	(0.66)	(1.7)
factor(region)Middle	-0.06**	-0.12**	-0.46**
	(0.03)	(0.06)	(0.21)
factor(region)Northeast	-0.07***	0.20**	-0.71**
	(0.02)	(0.09)	(0.27)
factor(region)West	-0.10***	-0.34***	-0.91***
	(0.02)	(0.10)	(0.25)
log (Proximity) × Port	-0.03	-0.01	0.02
	(0.03)	(0.06)	(0.15)
Fit statistics			
Observations	16,794	16,794	16,794
R^2	0.22604	0.24178	0.35460
Adjusted R^2	0.22577	0.24150	0.35437

Clustered (County) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

significant (β=−0.14, $p < 0.01$), suggesting that more remote areas experience higher pollution levels. This outcome implies that while such regions may have lower economic development, they also suffer from weaker environmental regulation.

Notably, interaction effects reveal that significant political events, such as the 20th CPC Congress, mitigate pollution levels in more distant regions, evidenced by the positive and significant interaction term (β=0.02, $p < 0.01$). This finding implies that high-profile political initiatives can enhance regulatory efforts, even in less accessible areas.

The combined empirical findings suggest that proximity to provincial capitals is a strong determinant of regional development through urban and industrial growth. However, this economic advantage comes with varying levels of environmental regulation. Regions closer to provincial centers benefit from better governance capacity, which helps mitigate pollution even amidst heightened economic activity. Conversely, more remote regions, despite having lower economic development, face higher pollution

Table 3: Relationship between Activities, Pollution, and Proximity

Dependent Variable:	log (NO2)					
Model:	FEOLS (1) (1)	FEOLS (2) (2)	FEOLS (3) (3)	FEOLS (4) (4)	FEOLS (5) (5)	FEOLS (6) (6)
Variables						
log (Built-up area)	1.6***	1.6***	1.9***	2.5***	1.1***	
	(0.15)	(0.15)	(0.12)	(0.41)	(0.13)	
log (Total Population)	0.08***	0.08***	0.08***	0.14***	0.06***	0.18***
	(0.02)	(0.02)	(0.02)	(0.03)	(0.02)	(0.03)
Congress		-0.08***			-0.30***	
		(0.01)			(0.08)	
COVID		-0.04**				
		(0.01)				
Port			1.3***			
			(0.35)			
log (Built-up area) × Port			-0.86***			
			(0.17)			
Port × log (Total Population)			-0.09***			
			(0.03)			
Capital				1.0		
				(0.65)		
log (Built-up area) × Capital				-1.0**		
				(0.40)		
Capital × log (Total Population)				-0.06		
				(0.05)		
log (Proximity)					-0.14***	-0.22***
					(0.01)	(0.03)
log (Proximity) × Congress					0.02***	
					(0.007)	
built_level						-1.5**
						(0.70)
built_level × log (Proximity)						0.16**
						(0.06)
Fixed-effects						
County	Yes	Yes	Yes		Yes	
Year	Yes		Yes	Yes		Yes
Fit statistics						
Observations	16,794	16,794	16,794	16,794	16,794	16,794
R^2	0.80465	0.79386	0.81353	0.51928	0.82865	0.42357
Within R^2	0.42430	0.41660	0.45049	0.51245	0.51506	0.41538

Clustered (County) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

levels due to limited regulatory effectiveness. These insights underscore the importance of tailored environmental policies that address the unique challenges faced by distant regions to balance economic growth with environmental protection.

5 Conclusion

This study explores the relationship between geographical proximity to provincial capitals, regional development, and environmental outcomes in China. The research was motivated by the hypothesis that closer proximity to administrative centers enhances economic development due to increased access to political and economic resources,

which can influence environmental regulation and pollution levels.

We began by discussing the theoretical framework that proximity impacts local governments' capacity for governance and regulation. This hypothesis was tested using a dataset comprising satellite-derived NO2 concentration data as a proxy for pollution, combined with development metrics such as urban extent, population, and the number of industrial units. Our analysis employed regression models incorporating interaction terms to capture the mediating effect of proximity on the relationship between economic development and pollution.

The results confirmed that regions closer to provincial capitals generally exhibit higher levels of urbanization and industrial activity. However, these areas also benefit from stronger regulatory frameworks, mitigating pollution despite increased development. In contrast, more remote regions demonstrated higher pollution levels, likely due to weaker regulatory enforcement, even when economic activities were less intensive. Significant interaction effects, such as those involving political events like the 20th CPC Congress, illustrated how proximity interacts with governance efforts to influence environmental outcomes.

Due to time constraints and data limitations, particularly the lack of county-year variation in economic and demographic indicators, we were unable to conduct a comprehensive panel data analysis and apply a two-way fixed effects model. This limitation restricts the ability to fully capture temporal dynamics and potential confounding factors across different periods.

To enhance the identification strategy in future research, a more robust approach would include constructing a comprehensive panel dataset with county-year variation in economic, demographic, and environmental indicators. This would allow for the use of panel data methods, such as two-way fixed effects models, to better control for time-invariant unobserved heterogeneity and time trends. Incorporating a Difference-

in-Differences (DID) approach could strengthen causal inference by comparing changes in outcomes between regions with varying proximities to provincial capitals before and after specific policy interventions or regulatory shifts.

Furthermore, collecting data on more granular, updated measures of regional development and environmental regulations will improve the model's precision. Expanding the scope to include additional satellite-based environmental data (e.g., particulate matter or greenhouse gas emissions) will provide a more comprehensive view of pollution and environmental impact. This enhanced approach will help to better understand how geographical proximity influences political institutions' actions and how those actions affect environmental outcomes.

Overall, this study contributes to understanding the dual role of proximity to provincial capitals in fostering economic development while influencing environmental regulation and outcomes. Policymakers must consider these dynamics to design targeted strategies that address regional disparities in governance capacity, thereby balancing economic growth and environmental sustainability.

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