

Urbanisation-Environment Coupling Coordination: Evidence from Anhui's Urban Agglomerations

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Abstract

Under the constraints of China's 'dual carbon' goals, coordinating between urbanisation and environment has become a key challenge for regions undergoing rapid structural transformation. Focusing on eight prefecture-level cities in Anhui Province, this paper examines coupling coordination over the period 2018-2023. By constructing comprehensive indicator systems, the coupling coordination degree is measured, and its spatiotemporal evolution is evaluated. A fixed-effects panel regression framework is employed to investigate the role of economic development and the moderating effect of population density. The results indicate that, during the analysis period, the coupling coordination degree increased steadily, suggesting a gradual transition from a relatively low level of coordination toward a more balanced and synergistic development stage, although inter-city disparities persist. The regression analysis shows that economic development is positively associated with the coupling coordination degree, highlighting the role of development quality in supporting urban-environmental interaction. Moreover, population density plays a positive moderating role. However, given the composite nature of the coupling coordination degree and potential endogeneity concerns, these findings should be interpreted as associational rather than causal.

Keywords: ‘Dual carbon’ goals, Coupling coordination degree, Economic development, Population density

1. Introduction

1.1 Introduce the Problem

Amid intensifying global climate change pressures, climate governance frameworks surrounding carbon peaking and carbon neutrality have increasingly become constraints on socio-economic development worldwide. As one of the world’s largest carbon-emitting countries, China is committed to achieving carbon peaking before 2030 and carbon neutrality before 2060 (Sun et al., 2022). This strategic pledge signifies that low-carbon development has shifted from a policy option to a long-term national strategy with strong regulatory force. Following the ‘dual carbon’ goals, the traditional development model that is characterised by high energy consumption, high emissions, and extensive use of factors of production is no longer sustainable. Thus, the logic of urbanisation is undergoing a fundamental transformation. As urbanisation is one of the most carbon-intensive aspect of economic activity (Wang et al., 2023), its transition plays a decisive role in determining whether national mitigation targets can be achieved.

As carbon constraints are tightened, the relationship between urbanisation and environmental systems has become increasingly complex, leading to more pronounced structural tensions at the regional scale. On the one hand, cities must continue to accommodate population concentration, industrial upgrading, and economic growth. This means that the urbanisation process is likely to persist over an extended period (Wei et al., 2024). On the other hand, stricter carbon limits impose growing demands on energy restructuring, industrial transformation, transport system upgrading, and spatial reconfiguration. Under these conditions, systematically assessing their coordination has emerged as a key scientific issue for regional sustainable development.

1.2 Explore Importance of the Problem

The challenge of coordinating urbanisation and environmental sustainability is particularly evident at the regional scale. Structural tensions emerge as regions attempt to balance long-term economic growth with increasingly binding ecological constraints.

As China’s most economically dynamic, highly urbanised integrated region, the Yangtze River Delta (YRD) urban agglomeration plays a key role in the national low-carbon transition. Nevertheless, substantial disparities persist within the region in terms of development stage and environmental conditions. At the intersection of the Yangtze River Economic Belt (YREB) and the YRD integration strategy, Anhui Province serves both as a major recipient of industrial transfer from the eastern coastal areas and as an increasingly important participant in the regional division of labour (Liu et al., 2022). At the same time, accelerated industrialisation and urban expansion have intensified ecological pressure, placing Anhui under particularly acute constraints between the need for rapid development and the imperative of green transformation. Compared with the core areas of the YRD, which have largely entered a late-stage of urbanisation focused on quality improvement, Anhui remains

in a phase of rapid urban growth (Xie et al., 2024). This developmental context makes it more likely that tensions among scale expansion, structural adjustment, and carbon constraints will be exposed, giving the area strong representativeness for analysing the coordinated relationship of urbanisation and environment.

1.3 Describe Relevant Scholarship

Studies on urbanisation-environment coordination rely on a scientific and operational evaluation framework. Early research often measured urbanisation using single indicators such as urbanisation rates (Li et al., 2022). Since China's 18th National Congress, however, the 'new-type urbanisation' strategy has shifted scholarly attention from scale expansion to quality improvements, with more emphasis on economic restructuring, public services, infrastructure provision, and spatial efficiency. Environmental assessment is typically based on composite indicators capturing pollutant emissions, ecological conditions, and governance capacity (Jain & Mohapatra, 2023). The Pressure-State-Response (PSR) framework has been widely adopted to structure the environmental subsystem, reflecting the dynamic interactions between human activities and ecosystems (Zhang et al., 2023). Compared to single-pollutant measures, composite indices are better suited to capturing overall ecological sustainability and regulatory performance under tightening environmental constraints.

Within this context, the coupling coordination degree (CCD) has emerged as an important analytical tool. The CCD is defined as a system-level metric that captures the degree of coordinated development between new urbanisation and the ecological environment. It does not represent a direct economic outcome, but rather reflects the dynamic interaction, mutual constraints, and co-evolution of the two subsystems (Wang et al., 2021). CCD embodies a holistic evaluation framework that integrates multiple dimensions of urban and environmental performance, thereby overcoming the limitations of single-indicator approaches.

Empirical studies have increasingly applied CCD models alongside panel econometric methods to identify key driving factors, including economic development, population density, and governance capacity (Luo et al., 2022; Zhao et al., 2022; Shao & Razzaq, 2022; Wang & Yang, 2023; Chen et al., 2023; Zeng et al., 2023). While these studies provide valuable insights, most analyses are conducted at national or large regional scales, with limited attention to intra-provincial heterogeneity.

1.4 State Hypotheses and Their Correspondence to Research Design

Despite the growing body of literature, several gaps remain. First, existing evaluation systems are often designed for large-scale analysis and may not adequately reflect the structural characteristics of small- and medium-sized cities. Second, many studies treat provinces as homogeneous units, overlooking internal disparities and limiting the understanding of region-specific dynamics.

To address these limitations, this paper focuses on Anhui Province within the YRD urban agglomeration. It constructs a locally adapted evaluation system for urbanisation and the environment and measures the CCD at the city level. Building on the theoretical framework and existing empirical findings, this paper is guided by the three analytical expectations. First,

the interaction between urbanisation and environmental systems is expected to be dynamic rather than static. Second, economic development is expected to promote coordination, although its effects may vary across cities depending on structural conditions. Third, population agglomeration may influence coordination positively by generating scale effects, improving resource allocation, and supporting infrastructure efficiency.

To examine these mechanisms, the paper adopts a combined approach of CCD measurement and panel regression analysis, allowing for the identification of driving factors and the exploration of intra-urban heterogeneity. The analysis focuses on spatiotemporal evolution and influencing mechanisms, rather than establishing strict causal inference.

2. Method

2.1 Area and Data

This paper examines the Anhui cities within the YRD urban agglomeration. Considering the officially recognised spatial framework of YRD integration, this area includes eight prefecture-level cities in Anhui Province: Hefei, Wuhu, Ma'anshan, Tongling, Anqing, Chuzhou, Chizhou, and Xuancheng (Outline of the Integrated Development Plan for the Yangtze River Delta Region, 2019). These cities are in the eastern and central parts of Anhui and form the province's main interface with the core YRD region. Recently, these cities have played a key role in industrial transfer, population agglomeration, and regional coordination under the YRD integration strategy. At the same time, rapid urban expansion and industrial development have placed increasing pressure on local ecological systems, making the region a representative case.

The study period spans from 2018 to 2023, a stage during which China's low-carbon development agenda and the YRD integration strategy were advanced significantly. The data used in this paper are obtained primarily from official statistical sources, ensuring consistency and reliability. Socio-economic and urbanisation-related indicators are collected from the Anhui Statistical Yearbook, municipal statistical yearbooks, and annual statistical bulletins of the eight sample cities. Environmental and ecological indicators are compiled from local environmental statistical reports and relevant government agency websites, including ecological and environmental monitoring platforms. All indicators are verified for consistency, while missing values are handled using standard interpolation methods to ensure data comparability across cities and over time.

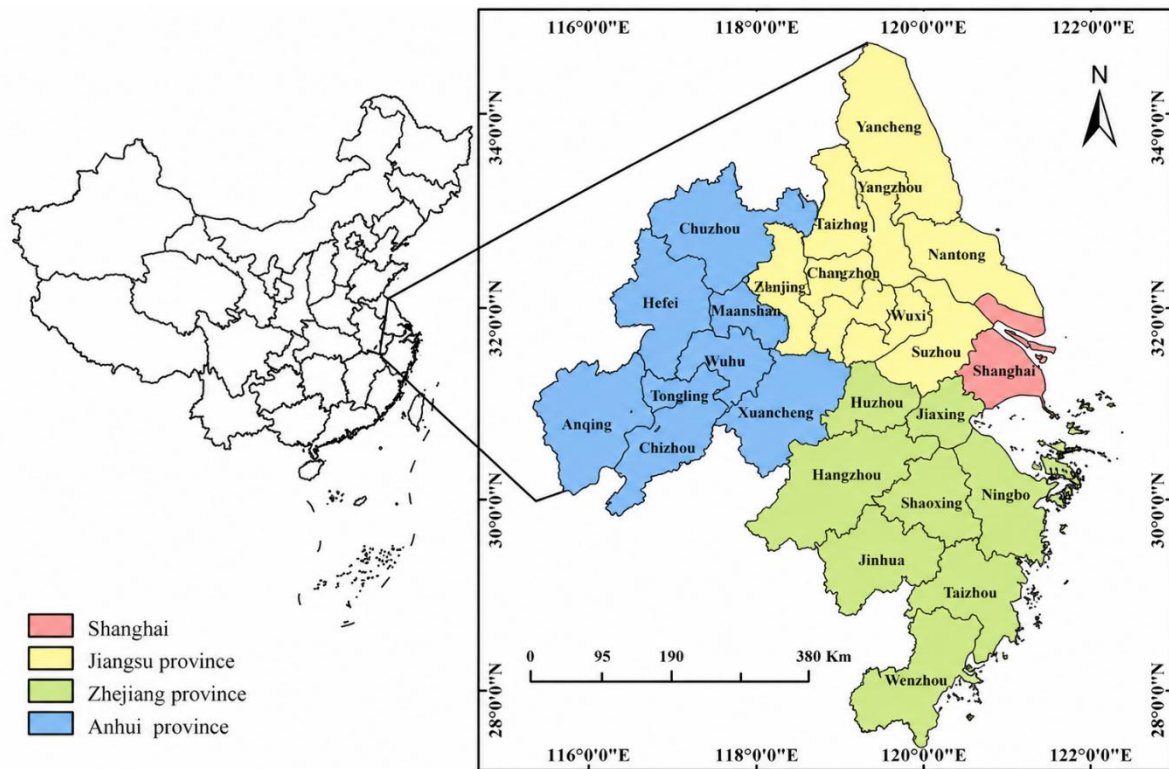


Figure 1. Anhui Cities Within the YRD Urban Agglomeration

Source: Redrawn By the Authors Based on Open-Source Administrative Boundary Data

Figure 1 illustrates the geographical location and administrative composition of the Anhui cities within the YRD. The right panel presents the spatial distribution of prefecture-level cities in Anhui, indicating the regional scope.

2.2 Indicator Construction

To evaluate the CCD, this paper constructs a comprehensive indicator system for both subsystems. Indicator selection follows the principles of scientific relevance, data availability, and comparability across cities and over time.

To reflect quality-oriented transformation, the urbanisation subsystem is measured using multiple dimensions (Zou et al., 2023). Indicators are selected to capture economic development, spatial expansion, social services, and infrastructure provision. The environment subsystem is designed to represent the state of environmental conditions and governance capacity. Indicators focus on environmental pressure, state, and response, encompassing resource consumption, pollutant emissions, and environmental treatment (An et al., 2025). This framework reflects the interaction between human activities and natural systems and enables evaluation of environmental sustainability under increasing development and carbon constraints.

Table 1. Evaluation Indicator System

System Level	Dimension Level	Indicator Level	Unit	Attribute
Urbanisation	economic	urbanisation rate	%	+
		average wage of employees in urban non-private units	Yuan	+
		proportion of tertiary industry in GDP	%	+
	spatial	per capita urban road area	m ²	+
		built-up area	km ²	+
		drainage pipe density in built-up areas	km/km ²	+
	social	proportion of public budget revenue in GDP	%	+
		proportion of education expenditure in public budget expenditure	%	+
	infrastructure	number of beds in hospitals and health centres	beds	+
		total collection of public libraries	1000 books	+
Environment	pressures	industrial wastewater discharge	10 kilotons	–
		industrial sulphur dioxide emissions	ton	–
	states	comprehensive utilisation rate of solid waste	%	+
		proportion of days with good air quality	%	+
		green coverage rate of built district	%	+
	responses	harmless disposal rate of municipal solid waste	%	+
		sewage treatment rate	%	+
	per capita park green space	m ²	+	

Table 1 presents the composite indicator system that was developed for the two subsystems of Urbanisation and the environment. The urban subsystem is structured around four dimensions, which collectively capture population and industrial concentration, spatial carrying capacity, public service provision, and infrastructural support, reflecting the overall quality and structural characteristics of urban development. The environmental subsystem is developed in accordance with the Pressure-State-Response framework. The pressure dimension is used to measure industrial pollutant emissions. The state dimension reflects environmental quality and ecological conditions. The response dimension represents environmental governance and the capacity for ecological restoration. All indicators are treated as positive, except those relating to pollutant emissions, which are defined as negative indicators. The indicator system provides the empirical foundation for subsequent index calculation and coupling coordination analysis.

All raw data are first normalised using a range-standardisation method to ensure comparability across indicators with different units and scales. Positive indicators, where higher values indicate better performance, and negative indicators, where higher values indicate greater environmental pressure, are treated separately to maintain a consistent direction. Following normalisation, indicator weights are determined using the entropy method, assigning weights based on the degree of variation in each indicator (Wu et al., 2022). This data-driven approach reduces subjectivity while enhancing the robustness of the composite indices. The weighted indicators are aggregated to construct comprehensive indices, serving as the basis for subsequent coupling coordination analysis.

2.3 Coupling Coordination Degree Model

To examine the coordination relationship between urban and environment, this paper applies the CCD model. Let U_u and U_e denote the comprehensive index of the urbanisation and environment subsystems. Following data normalisation and entropy-based weighting, the composite indices are obtained as weighted sums of the corresponding indicators as follows:

$$U = \sum_{j=1}^k (W_j \times Z_{itj}) \quad (1)$$

Where U represents the comprehensive index, W_j represents the weight of each indicator.

Coupling emphasises the strength and intensity of interaction and coordination. The coupling degree is calculated as follows (Tan et al., 2022):

$$C_{ue} = \frac{2\sqrt{U_u \cdot U_e}}{U_u + U_e} \quad (2)$$

To account for the combined development level of the two subsystems, a coordination index is constructed as follows:

$$T_{ue} = \alpha U_u + \beta U_e \quad (3)$$

where T_{UE} represents the coordination degree, reflecting the level of synergistic development between the systems; α and β represent the weight coefficients of the two subsystems. To mitigate the potential bias caused by subjective weighting, this paper adopts an equal weighting approach: $\alpha = \beta = 0.5$ (Dang et al., 2024).

$$CCD_{ue} = (C_{ue} \times T_{ue})^{\frac{1}{2}} \quad (4)$$

where CCD_{ue} is an important indicator for measuring the degree of synergistic evolution between the two subsystems. It represents the geometric mean of the C_{ue} and the T_{ue} , which can be used to evaluate the overall level of coordinated development of the two systems under their interaction. The value range is: $CCD_{ue} \in [0,1]$.

Table 2. The Classification Standard for CCD Grades

The D Value Range	Rank of Harmony Degree	Level
[0.0~0.1)	1	Extremely disordered
[0.1~0.2)	2	Severely disordered
[0.2~0.3)	3	Moderately disordered
[0.3~0.4)	4	Mildly disordered
[0.4~0.5)	5	Marginally disordered
[0.5~0.6)	6	Barely coordinated
[0.6~0.7)	7	Primary coordination
[0.7~0.8)	8	Intermediate coordination
[0.8~0.9)	9	Good coordination
[0.9~1.0]	10	Excellent coordination

Based on the CCD values, the coordinated development status of each city can be evaluated and classified into different stages (Table 2). This measure provides a consistent and comparable framework for analysing spatial differences and temporal changes in coordination levels (Wu et al., 2024).

It should be noted that the CCD is a composite indicator constructed from multiple dimensions of urbanisation and environmental performance. As such, it is interpreted as a system-level coordination metric, rather than a direct economic outcome variable. While this approach enables a comprehensive assessment of interaction between subsystems, it may introduce potential mechanical correlations with certain explanatory variables, particularly those related to economic development. To address this concern, this study conducts additional robustness checks, including alternative specifications and sensitivity analyses, to ensure that the main findings are not driven by index construction.

2.4 Econometric Model

This paper develops an econometric framework to examine the impact of economic development on the CCD, focusing on the moderating role of population density.

Economic development is widely regarded as a key driver for coordination between urbanisation and environment (Chen et al., 2023). Improvements in income levels enhance fiscal capacity, promote technological progress, and facilitate industrial upgrading, all of which contribute to more efficient environmental management and a gradual decoupling of economic growth from ecological pressure. Within the context of YRD integration, cities in Anhui Province benefit from increased factor mobility, industrial spillovers, and coordinated regional policies, which may further strengthen the positive role of economic development in fostering coordinated urban-environmental development. Accordingly, this paper proposes the two hypotheses.

H1: *Economic development has a significant positive effect on the coupling coordination degree between urbanisation and the environment.*

However, the effect of economic development on CCD is unlikely to be homogeneous across cities, as it may depend on local conditions related to population agglomeration (Guo et al., 2024). Population density is widely recognised as a key factor shaping urban dynamics and environmental pressure. On the one hand, higher population density may intensify land use, energy consumption, and environmental stress, weakening the positive influence of economic development on CCD (Liu et al., 2022). On the other hand, population agglomeration may generate scale and agglomeration effects, which could amplify the coordinating effect of economic development. These competing mechanisms suggest that population density may condition the marginal impact of economic development on CCD. This paper proposes the following hypothesis accordingly:

H2: *Population density moderates the relationship between economic development and the CCD.*

This paper takes CCD as the dependent variable. The explanatory variables are categorised

into three groups: (1) economic development (ECO_{it}) is measured by per capita GDP, serving as the core explanatory variable for testing the hypothesis; (2) government investment (GOV_{it}) is proxied by the proportion of public fiscal expenditure to GDP, which reflects the intensity of government involvement in economic development and public service provision; (3) population density ($PopD_{it}$) is included as a control variable and its interaction with economic development as a moderating variable. This specification allows the model to explicitly assess whether and how the marginal effect of economic development on CCD varies with differing levels of population agglomeration.

Table 3. Description of Variables

Variable	Definition and Measurement	Expected Sign
Coupling Coordination Degree (CCD)	Calculated using the CCD model based on the composite indices at the city level.	/
Economic Development (ECO_{it})	Measured by per capita GDP, reflecting the stage and capacity of urban economic development.	+
Government Investment(GOV_{it})	Proxied by the proportion of public fiscal expenditure to GDP, reflecting the intensity of government involvement.	+
Population Density ($PopD_{it}$)	Measured by the ratio of the resident population to the built-up area, reflecting the level of population agglomeration.	+

The econometric specification is as follows:

$$CCD_{it} = \beta_1 ECO_{it} + \beta_2 GOV_{it} + \beta_4 PopD_{it} + \beta_3 (ECO_{it} \times PopD_{it}) + \alpha_i + \varepsilon_{it} \quad (5)$$

where α_i is the individual effects reflect the specific intercept of the individual. The fixed-effects approach controls for time-invariant heterogeneity and common shocks, allowing for the estimation of conditional relationships between variables. However, despite the robustness checks implemented, potential endogeneity concerns cannot be fully eliminated. Therefore, the estimated coefficients should be interpreted as robust associations

3. Results

3.1 Coupling Coordination Degree Analysis

This section presents the empirical results of the CCD evaluation. The resulting CCD values provide a dynamic and comparable measure of urban-environmental coordination over time. The detailed results are presented in Figure 2.

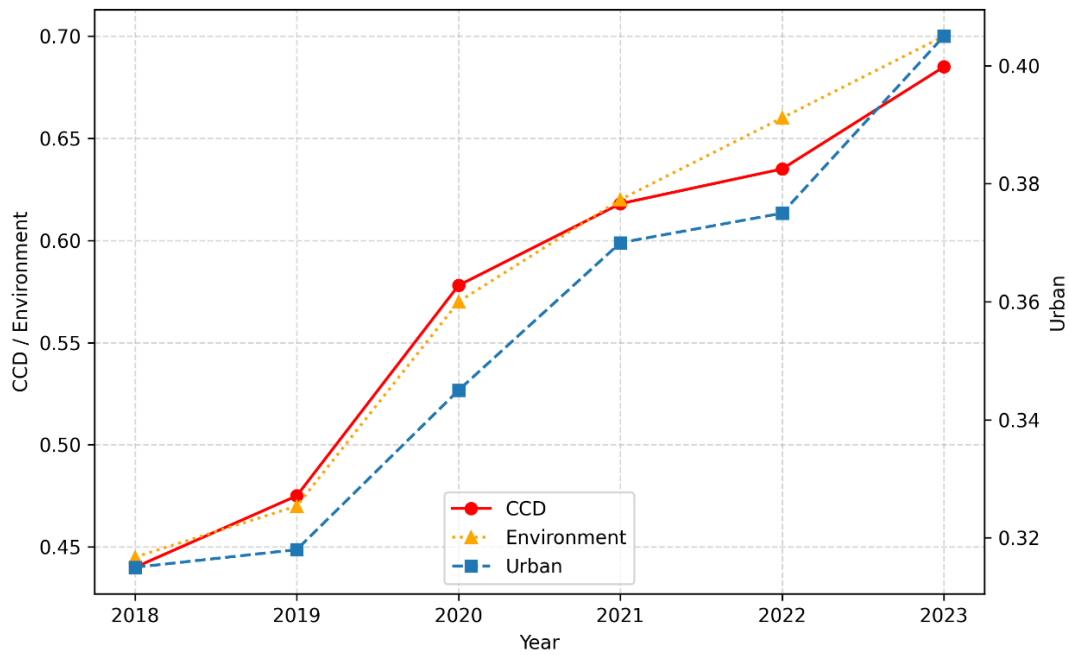


Figure 2. Trends of CCD, UD, and EC in Anhui city clusters

Figure 2 indicates the temporal evolution of the urban index, the environment index, and the CCD from 2018 to 2023. All three indicators exhibit a clear upward trend, suggesting continuous improvement in urban ecological conditions and the level of coordination. Particularly, a steady increase in CCD suggests a gradual transition from weak coordination towards a more coordinated development stage, reflecting stronger synergistic interactions and coordination.

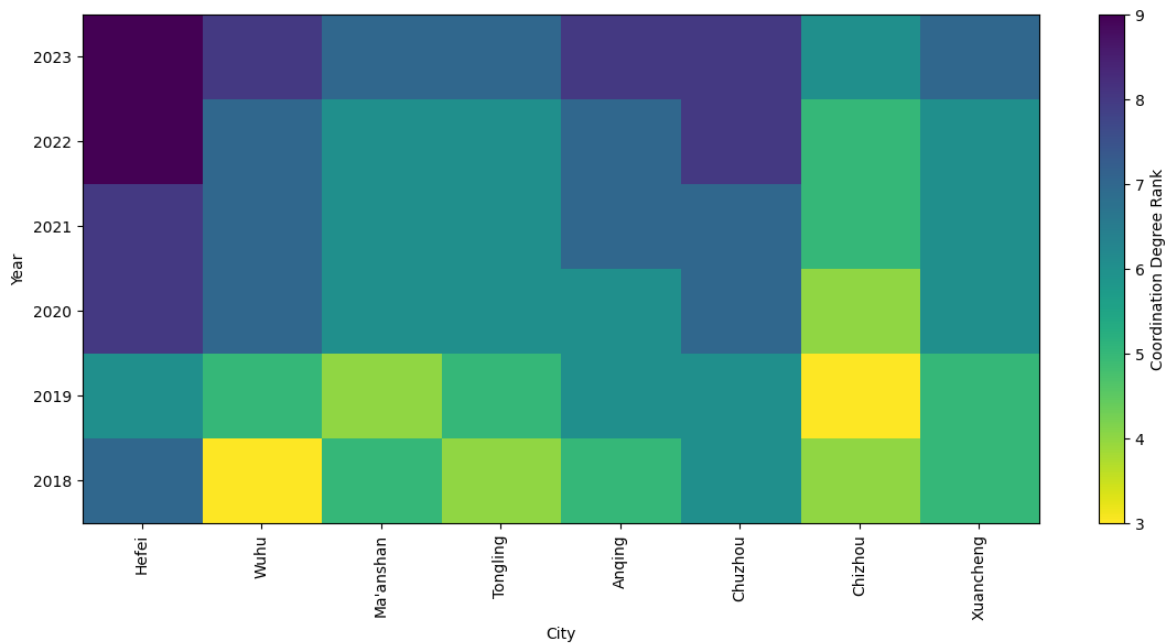


Figure 3. The CCD Levels of Each City

Figure 3 shows substantial spatiotemporal heterogeneity in CCD ranks across cities. While most cities experience an upward shift in coordination levels over time, consistent with the regional trend, substantial inter-city disparities persist, with core cities maintaining higher coordination levels than the periphery.

3.2 Panel Regression Analysis

3.2.1 Descriptive Statistics

Table 4. Descriptive Statistics for Variables

Variable	P50	Mean	SD	Min	Max
CCD	0.573	0.571	0.138	0.218	0.832
ECO	83479	85133.08	23977.63	41088	130074
GOV	0.162	0.161	0.037	0.107	0.225
PopD	391.965	433.116	216.862	156.8	860.72

Table 4 presents the descriptive statistics of the main variables. The CCD has a mean value of 0.571, with a wide range from 0.218 to 0.832. This finding indicates substantial heterogeneity in the level of urban-environmental coordination. Economic and population density both exhibit considerable dispersion, reflecting pronounced differences in economic development and population agglomeration. Comparatively, government investment exhibits relatively limited variation, indicating a stable level of government involvement during the analysis period.

3.2.2 Correlation Analysis

Table 5. Correlation Matrix for Variables

Variable	CCD	ECO	GOV	PopD	ECO* PopD
CCD	1.000				
ECO	0.489*** (0.000)	1.000			
GOV	-0.380*** (0.008)	-0.853*** (0.000)	1.000		
PopD	0.370*** (0.009)	0.648*** (0.000)	-0.810*** (0.000)	1.000	
ECO* PopD	0.118 (0.423)	0.073 (0.622)	-0.088 (0.552)	0.194 (0.187)	1.000

Notes: Asterisk ***, **, and * represent 1, 5, and 10 percent levels of significance, respectively. The figures in brackets are p-values.

Table 5 presents the correlation matrix for the main variables. The results indicate that CCD is significantly and positively correlated with economic and population density. This finding suggests that higher economic development and population agglomeration are generally associated with greater urban-environmental coordination. Comparatively, government investment is significantly and negatively correlated with CCD, which is more likely to reflect the compensatory and policy-responsive nature of fiscal spending in practice.

Generally, governments tend to allocate more resources to cities with lower levels of coordination to mitigate development imbalances and ecological constraints (Zhang et al., 2024). Thus, to more precisely identify the net effect of government investment on CCD, it is necessary to employ regression analysis that controls for other influencing factors.

Table 6. Multicollinearity Test

Variable	VIF	1/VIF
GOV	6.38	0.157
ECO	3.75	0.267
PopD	3.10	0.322
ECO × PopD	1.05	0.948
Mean VIF	3.57	

Table 6 presents the VIF statistics for the explanatory variables after mean-centring. The VIF values for government investment and economic development are 6.38 and 3.75. The interaction term between them exhibits a VIF close to unity. The mean VIF is 3.57, which is well below the commonly used threshold of 5. This finding indicates that multicollinearity is unlikely to pose a serious concern. The findings suggest that the mean-centring procedure effectively mitigates potential collinearity arising from the inclusion of the interaction term.

3.2.3 Basic Regression Analysis

Table 7. Results of Static Panel Data Models

Variable	Pooled OLS	RE	FE	FE (Robust Standard Errors)
ECO	0.299** (0.014)	0.532*** (0.000)	0.614*** (0.000)	0.614*** (0.001)
GOV	1.391 (0.269)	1.566* (0.057)	1.610** (0.042)	1.610** (0.047)
PopD	0.062 (0.301)	-0.017 (0.801)	0.152 (0.479)	0.152 (0.523)
ECO×PopD	0.064 (0.671)	0.258** (0.018)	0.330*** (0.002)	0.330** (0.019)
Constant	0.340* (0.096)	0.292** (0.029)	0.278** (0.028)	0.278** (0.042)
R ²	0.271	Overall R ² =0.237	Within R ² =0.746	0.746
rho	-	0.595	-	-
F-test			23.71*** (0.000)	
BP-LM Test	41.65*** (0.000)			
Hausman Test		14.61*** (0.006)		
Heteroskedasticity Test	52.75*** (0.000)			
Serial Correlation	3.451 (0.106)			

Notes: Asterisk ***, **, and * represent 1, 5, and 10 percent levels of significance, respectively. The figures in brackets are p-values.

Table 7 presents the results from pooled OLS, random effects, and fixed effects (FE) estimations. Model specification tests, including the F-test, the BP-LM test, and the Hausman test, show that the FE model is the preferred specification. These findings suggest that unobserved city-specific heterogeneity plays an important role in explaining variations. Under the FE framework, economic development exhibits a significantly positive coefficient. This finding confirms that economic development is positively associated with the CCD. Once city specific characteristics are controlled, government investment also shows a positive effect. Moreover, the interaction term between economic development and population density is positive and statistically significant, though population density alone does not have a significant effect.

The empirical results provide clear support for Hypothesis 1, which posits that economic development positively influences the CCD. Furthermore, a significantly positive interaction term between economic development and population density supports Hypothesis 2. This finding indicates that population density plays a moderating role by strengthening the positive effect of economic development on coordination outcomes.

3.3 Robustness Test

To address concerns related to potential endogeneity and the composite nature of the CCD, a set of robustness checks is conducted to examine the stability of the baseline results. These checks aim to mitigate simultaneity bias, reduce potential mechanical correlation, and evaluate sensitivity to alternative specifications.

In the first instance, lagged values of economic development are incorporated into the FE model. Using the one-period lag helps to reduce simultaneity concerns by weakening the possibility that current coordination levels influence economic performance. The results remain consistent in both sign and statistical significance, suggesting that the observed relationship is not primarily driven by reverse causality.

In addition, an alternative CCD measure is constructed by excluding indicators closely associated with economic development from the urbanisation subsystem. This adjustment reduces direct overlap between the dependent variable and the core explanatory variable, while still capturing the overall coordination between systems. The regression results based on this adjusted index remain qualitatively similar to the baseline findings.

Furthermore, the specification is extended by incorporating additional control variables, including education expenditure, to account for variation in human capital and public investment structures across cities. The inclusion of these controls does not materially affect the estimated coefficients of the main variables.

Table 8. Robustness Analysis

Variable	(1) Baseline FE	(2) Lagged ECO	(3) Adjusted CCD	(4) Additional Controls
ECO	0.614*** (0.001)	0.394*** (0.000)	0.486*** (0.003)	0.676*** (0.000)
GOV	1.610** (0.047)	-0.856 (0.351)	0.807 (0.215)	2.192** (0.011)
PopD	0.152 (0.523)	-0.080 (0.643)	0.251 (0.292)	0.005 (0.983)
ECO×PopD	0.330** (0.019)	0.209** (0.026)	0.407*** (0.007)	0.327*** (0.002)
EDR	/	/	/	2.878* (0.098)
Constant	0.278** (0.042)	-3.251** (0.028)	0.405*** (0.005)	-0.267 (0.441)

Notes: Asterisks***, ** and * denote significance levels at 1%, 5% and 10%, respectively. Column (1) reports baseline FE results. Column (2) uses lagged economic development. Column (3) uses adjusted CCD excluding economic-related indicators. Column (4) adds education expenditure as a control variable.

Table 8 presents the results of the robustness checks. These results indicate that the main findings are robust across alternative specifications and measurement approaches.

4. Discussion

This paper set out to examine the coordination between urbanisation and the environment in Anhui cities within the YRD urban agglomeration. The empirical results provide support for the primary hypothesis that economic development is positively associated with the CCD. In addition, the moderating role of population density is partially supported, as the interaction term between economic development and population density is positive and statistically significant, while the direct effect of population density remains insignificant.

The observed improvement in CCD over time is consistent with the broader context of China's low-carbon transition and regional integration policies. These findings suggest that urbanisation and environmental systems are increasingly evolving in a more coordinated manner, although disparities across cities remain evident. This pattern aligns with existing studies that emphasise the role of policy frameworks and institutional coordination in promoting balanced development (Patel & Raval, 2024; Chen et al., 2023; Zheng et al., 2022).

The positive association between economic development and CCD is in line with previous research suggesting that higher income levels are linked to stronger fiscal capacity, technological advancement, and governance effectiveness (Zhang et al., 2022; Li et al., 2024). These factors are often associated with improved environmental management and more efficient resource allocation. The results indicate that population density conditions this relationship, implying that agglomeration effects may influence how economic development relates to coordination outcomes (Cai et al., 2023; Chen et al., 2024). In more densely populated areas, economies of scale and infrastructure sharing may enhance coordination,

whereas in less dense areas, such effects may be weaker or absent.

Despite these findings, several factors should be considered when interpreting the results. First, potential sources of bias cannot be fully ruled out. Although the fixed-effects model controls for time-invariant heterogeneity, issues such as reverse causality and omitted variables may still affect the estimates. Second, the CCD, as a composite indicator, may introduce measurement-related limitations, including mechanical correlations with explanatory variables. Third, the relatively small sample size may limit statistical precision and reduce the ability to detect more nuanced relationships. Also, this paper focuses on Anhui cities; the observed relationships may not fully apply to regions with different development stages or institutional environments. Future research could extend the analysis to a broader spatial scope or incorporate longer time series to examine whether similar patterns hold in other contexts.

Building on these empirical findings, several policy implications emerge.

From a governmental perspective, improving urban-environmental coordination requires not only economic growth but also the capacity to translate development gains into environmental outcomes. For Anhui and the broader YRD region, policy efforts may benefit from shifting towards coordination-oriented governance, with greater emphasis on integrated planning in land use, transport systems, and environmental regulation. Strengthening cross-city coordination could improve infrastructure efficiency and reduce redundant environmental costs in highly integrated regions. Given the heterogeneity across cities, differentiated strategies are also important. Less-developed cities may prioritise capacity building and green industrial transformation, while more advanced cities may focus on innovation-driven environmental management.

From an enterprise perspective, firms play a critical role in supporting coordinated development. Enterprises in densely clustered urban areas may benefit from agglomeration economies, such as knowledge spillovers and shared infrastructure, which can facilitate the adoption of cleaner production technologies. Strengthening energy efficiency, reducing emissions, and integrating environmental considerations into business strategies may help firms align with low-carbon development objectives while maintaining long-term competitiveness.

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Author contributions

Dr. He and Prof. Puah were responsible for study design and revising. Dr. He was responsible

for data collection. Dr. He drafted the manuscript and Prof. Puah revised it. All authors read and approved the final manuscript. All authors contributed equally to the study.

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Data sharing statement

No additional data are available.

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