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Coupling and Coordinated Development of Environmental Regulation and the Upgrading of Industrial Structure: Evidence from China's 10 Major Urban Agglomerations

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Abstract: Exploring the coupling and coordinated development of formal and informal environmental regulation, as well as their impact on the upgrading of the industrial structure of urban agglomerations, represents a new breakthrough. The comprehensive index of formal environmental regulation, informal environmental regulation, and industrial structure upgrading is calculated using the entropy method based on sample data from 127 cities in China's ten major urban agglomerations between 2003 and 2019. The characteristics of the coupling and coordinated development between formal and informal environmental regulation in these urban agglomerations are examined using a coupling coordination degree model. Furthermore, the effects of the coupling and coordinated development of formal and informal environmental regulation on the industrial structure upgrading in urban agglomerations are analyzed through fixed-effect and threshold regression models. The findings demonstrate that although the development of urban agglomerations remains unbalanced, the overall coupling coordination degree between formal and informal environmental regulation is increasing. Generally, the ten major urban agglomerations have transitioned from a state of reluctance coordination to primary coordination. The Pearl River Delta urban agglomerations have progressed from reluctance coordination to middle coordination, while the Yangtze River Delta, Shandong Peninsula, Central Plains, and Beijing–Tianjin–Hebei urban agglomerations have advanced from reluctance coordination to primary coordination. The remaining five urban agglomerations have shifted from near disorder to reluctance coordination. The coupling and coordinated development of formal and informal environmental regulation significantly promote the upgrading of the industrial structure in both overall and grouped samples of urban agglomerations, and the higher the degree of coupling coordination, the greater the promoting effect. Moreover, when informal environmental regulation is considered as a threshold variable, the coupling coordination degree exhibits a broken-line relationship with the industrial structure upgrading in urban agglomerations. Currently, the intensity of informal environmental regulations is relatively reasonable in China's ten major urban agglomerations, and the coordinated development of formal and informal environmental regulations has an impact on the industrial structure of urban agglomerations. Finally, this paper proposes corresponding suggestions encompassing the construction of an environmental regulation policy system, differentiated industrial policy, and the coordinated promotion of various policies.

Keywords: environmental regulation; coupling and coordinated development; upgrading of industrial structure; urban agglomerations; panel threshold regression models; panel data

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1. Introduction

Although China's economy developed rapidly in recent decades, the booming economy has also given rise to severe environmental problems (Yu 2014). The United Nations' Department of Economic and Social Affairs has established 17 sustainable development goals, including "Make cities and human settlements inclusive, safe, resilient and sustainable", which prioritize the need to pay attention to environmental problems resulting from the process of urbanization (United Nations 2020). As the most populous nation and a global economic powerhouse, China accounts for approximately 30% of worldwide carbon emissions and drives 73% of global emission growth (Shan et al. 2018). Consequently, China's advancements in environmental regulation play a pivotal role in shaping the global trajectory towards achieving carbon neutrality and peaking carbon emissions targets, underscoring its critical influence on international climate outcomes. However, compared to its geographical neighbor, Japan, China relies more on coal, which signifies that China may face a more difficult predicament in reducing carbon emissions (Ouyang and Lin 2017). Also, Yoon et al. (2020) pointed out that China is the net exporter of embodied carbon emissions to South Korea and Japan, which causes significant carbon leakage in China. Nevertheless, such a coal-dominated energy structure and international carbon leakage may also mean greater potential for further improvement. Thus, an effective environmental regulation system is desperately needed in China. Research has demonstrated that the development of an appropriate environmental regulation strategy can effectively constrain corporate conduct, facilitate the transformation of enterprise production methods, and drive the advancement of industrial structure (Chong et al. 2017; Du et al. 2021). In alignment with the 2025 Paris Agreement, China has committed to peaking carbon emissions by 2030, a pledge that necessitates further intensification of its environmental regulations. Presently, China's environmental regulation encompasses formal regulations, predominantly enforced by the government through coercive measures, and informal regulations led by the public, media, and environmental groups (Pargal and Wheeler 1996). These two forms of environmental regulation can, to a certain extent, complement each other and generate synergistic effects.

Delving into further detail, on the one hand, the dissemination of government environmental information and the imposition of penalties for environmental pollution serve to engage the public, media, and environmental groups in environmental protection efforts. On the other hand, the environmental protection demands voiced by the public, the exposure of pollution activities by the media, negotiations between environmental organizations and businesses, and government actions all function as oversight mechanisms for corporate production behavior and government enforcement actions. Consequently, they play a pivotal role in promoting the effective implementation of formal environmental regulatory policies. Thus, can the coupling and coordinated development of formal and informal environmental regulation contribute to the upgrading of the industrial structure? This is a question worth considering.

Additionally, De Goei et al. (2010) mentioned that the traditional central place conceptualization has already been outdated. Furthermore, in recent decades, urban agglomerations have emerged as one of the most important economic development carriers (Fang and Yu 2017), and have played an increasingly significant role in regional economic development (Yin et al. 2022a), which prioritizes the need to focus on urban agglomeration. Corresponding with the gradual revolution of "new-type urbanization" and "strategy for coordinated regional development", the construct of urban agglomeration becomes a crucial opportunity to boost Chinese high-quality economic development, and structure a "dual circulation" development pattern, which aims to make domestic and foreign markets boost each other, with the domestic market as the mainstay. Research indicates that ecological civilization serves as a crucial driving force for the development of new-style urbanization (Yu 2021). Due to the comprehensive and complex nature of urban agglomerations, the implementation of the "new urbanization" strategy and regional development strategy has inevitably led to the emergence of complex and challenging issues that were not present in traditional single-city contexts. These issues include a range of environmental problems (Grimm et al. 2008), such as the urban heat island effect (Thompson and Perry 1997), and environmental degradation (Hashmi et al. 2021). In terms of industry, the main concerns are the demographic transition (Sato and Yamamoto 2005) and structural changes in industries resulting from the of industries concentration from peripheral cities to central cities (Lu and Tao 2009).

It is evident that the environmental and industrial structural issues of urban agglomerations are more intricate and representative. Furthermore, urban agglomerations play a leading role in China's economic, technological, and cultural development, serving as an important platform for China to participate in international market competition. The resolution of environmental pollution and disruption in urban agglomerations, as well as the upgrading of industrial structures, are crucial for enhancing the overall competitiveness of these agglomerations, which in turn affects China's international status and influence.

The remainder of this paper is organized as follows. The second part is a literature review. The third part introduces the methodology. The fourth part analyzes the results of coupling and coordination degree. The fifth part discusses the results of the empirical studies. The final part concludes this study and proposes corresponding policy suggestions.

2. Literature Review

Based on research conducted in the academic field, there is a substantial body of literature on the environmental regulations and industrial structure upgrading, primarily focusing on the following aspects:

One aspect is considering environmental regulations as a whole and examining their impact on industrial structure upgrading. Some authors indicate that strength environmental regulations can lead to an increase in the proportion of the service industry and the manufacturing industry (Chong et al. 2017). Yin et al. (2022b) argue that the impact of environmental regulation on industrial upgrading exhibits a U-shaped curve. Hu et al. (2020), using the four provinces of the Yangtze River Economic Belt (Hunan, Hubei, Jiangxi, and Anhui) as their research samples, found that in the process of environmental regulation affecting the upgrading of industrial structure, there are both substitution effects and complementary effects. Moreover, the substitution effects are greater than the complementary effects. Environmental regulation has a positive impact on the optimization and upgrading of the industrial structure in second-tier cities, third-tier cities, and cities below the third tier, but the degree of impact varies. Research from Cohen and Tubb (2018) shows that many existing papers are based on the Porter hypothesis, whereby environmental regulation can contribute to innovation. Wu and Liu (2021) indicate that innovation has a significant positive spatial spillover effect on the upgrading of industrial structure. Furthermore, previous research also argues that technological innovation has a significant mediation effect on industrial structure upgrading in some cities in China (Shao et al. 2021). The level of industrial structure optimization may also influence the effectiveness of environmental regulation. For example, based on varying levels of industrial structure optimization, Chen et al. (2019) examined the impact of environmental regulations on carbon dioxide emissions, and found that environmental regulations can contribute to carbon dioxide emissions if the level of industrial structural optimization is low. However, when the level of industrial structural optimization is high, such scenarios are inversed, and environmental regulations have a significant inhibitory effect on carbon dioxide emissions.

The second aspect is to categorize environmental regulations and examine their impact on industrial structure upgrading. Many existing studies classify environmental regulation into two types: formal environmental regulation and informal environmental regulation (Cole et al. 2005; Pargal et al. 1997; Ren et al. 2023). Some scholars use these two types of environmental regulations to, respectively, examine their effects on industrial structure upgrading, leading to different conclusions. Existing research indicates that informal environmental regulation can boost the upgrading of industrial structure and such a relationship has regional heterogeneity (Chen et al. 2022). Research from Yuan and Xie (2014) indicates that formal and informal environmental regulation have different mechanisms for influencing industrial restructuring. Li and Liu (2023) also argue that formal and informal environmental regulations have different impact pathways: formal environmental regulations boost economic development through the rationalization of industrial structure (*RIS*), while informal environmental regulations promote economic development through upgrading industry structure. Some other scholars conduct a more detailed categorization of environmental regulations. For instance, Chen et al. (2020) classify environmental regulation into three types: command and control, market incentive, and voluntary participation, aiming to show that environmental regulation can spur the upgrading of industrial structure, thus promoting high-quality economic development. Furthermore, some authors also suggest that market incentive environmental regulation plays a more important role in the upgrading of industrial structure than the other two types of environmental regulation (Wang et al. 2022). Considering that, compared to other developed countries in Asia like Japan, which has a relatively long history of encouraging individuals, environmental groups, and NGOs to participate in environmental regulation (Moshkal et al. 2023), China lags behind in informal environmental regulation compared to Japan (Lin et al. 2011). Additionally, in policy making, informal environmental regulation has not received sufficient attention in addressing non-compliant behaviors beyond the scope of formal environmental regulation (Shen et al. 2023). Given this situation, there is a need to develop a coupled and coordinated measurement of formal and informal environmental regulations to enable a broader scientific understanding of China's environmental regulation process and its impact on the economy.

Based on existing the literature, many studies focus solely on the linear relationship between environmental regulation and the upgrading of industrial structure (Lin and Xie 2023; Song et al. 2021). However, there could be a non-linear relationship between these two variables (Yang et al. 2021). Additionally, many existing studies adopt a relatively narrow approach to measure industrial structure upgrading. For example, many studies use the share of secondary or tertiary industries to represent industrial structure upgrading (Dong et al. 2020; Hao et al. 2020), but this does not fully capture the overall goal of upgrading, which is to achieve both rationalization and optimization of the industrial structure (Chen et al. 2019). Each dimension reflects a different aspect of industrial structure upgrading: rationalization focuses on internal coordination, balance, and resource allocation efficiency, while optimization directly reflects the outcomes of upgrading, indicating whether the economy is advancing to a higher level. Therefore, both dimensions are essential for a comprehensive evaluation of industrial structure upgrading.

Overall, the literature on environmental regulations and industrial structure upgrading is quite ample, but there is still room for further research. Firstly, most studies are conducted at the provincial, regional level, or international level, little research focuses on the perspective of urban agglomerations. This paper takes the ten major urban agglomerations in China as research samples, carefully considering the economic cluster development characteristics in these cities, which offers a fresh research perspective. Secondly, the existing literature mainly focuses on the overall impact of environmental regulations and the effects of different types of environmental regulations on industrial structure upgrading. There is limited research on the coupling and coordinated development of formal and informal environmental regulations and its impact on industrial structure upgrading. This paper, based on the analysis of the characteristics of the coupling and coordinated development of formal and informal environmental regulations, employs fixed-effects models and threshold regression models to empirically analyze the impact of the coupling and coordination relationship between these two kinds of environmental regulation on industrial structure upgrading, which brings novelty to the field and emphasizes the need to further develop both of them, especially informal environmental regulation. Thirdly, the measurement of environmental regulation indicators is currently relatively limited. This paper, based on data availability, selects six micro-level indicators to measure formal environmental regulations and two micro-level indicators to measure informal environmental regulations, providing a more comprehensive and scientifically grounded approach. Based on this, this paper selects the ten major urban agglomerations in China, which were among the first to develop and have a certain scale. These urban agglomerations include the Pearl River Delta, the Yangtze River Delta, Beijing–Tianjin–Hebei, Shandong Peninsula, West

Taiwan Strait, the Middle Reaches of the Yangtze River, the Central Plains, the Central and Southern Liaoning, Chengdu–Chongqing, and Guanzhong Plain as research samples. Table A1 details the cities included within these urban agglomerations. Finally, this paper focuses on exploring the non-linear relationship between the coupling and coordination degree of formal and informal environmental regulations and its impact on the upgrading of industrial structure in urban agglomerations. This paper aims to investigate the impact of the coupling and coordinated development of formal and informal environmental regulations on industrial structure upgrading in these urban agglomerations, with the goal of providing insights and recommendations for achieving "peak carbon" and "carbon neutrality" and promoting high-quality development.

3. Methodology

3.1. Explanation of Methodology Steps

The methodology contains 8 subsections, and the following 7 sections are organized as shown in Table 1.

Table 1. Explanation of methodology steps.

Step	Explanation	Method
Establishment of the Evaluation System	First, 6 variables and 2 variables were chosen to establish comprehensive indices for formal and informal environmental regulations, respectively. Next, the calculation of complex indices, including the rationalization of industrial structure and the optimization of industrial structure, was introduced. Finally, the process of the entropy method was described.	For the comprehensive indices system, please refer to Section 3.2 For an explanation of the indicators, please refer to Section 3.3 For the entropy method, please refer to Section 3.4
Calculation of Coupling and Coordination Degree	First, the coupling degree is calculated, followed by the calculation of the coupling coordination degree. Then, the classification criteria for the coupling coordination degree are established.	Coupling and coordination model (please refer to Sections 3.5 and 3.6)
Modelling	First, the baseline regression model is constructed. Then, the panel threshold regression model is constructed.	Fixed-effect model and panel threshold model (please refer to Section 3.7)

3.2. Measurement of Environmental Regulation and the Industrial Structure Upgrading

Environmental regulation includes two dimensions: formal environmental regulation (*FER*) and informal environmental regulation (*IER*). Due to the availability of data, a formal environmental regulation index system comprising six micro-indicators and an informal environmental regulation index system comprising two micro-indicators are constructed.

Following the research by Gan et al. (2011), we construct an industrial structure upgrading evaluation system comprising two dimensions: rationalization of industrial structure (*RIS*) and optimization of industrial structure (*OIS*). The indicator evaluation system is shown in Table 2. The data used mainly come from the "China City Statistical Yearbook", "China Statistical Yearbook on Environment", "China Statistical Yearbook for Regional Economy", "Statistical Communiqué of the PRC National Economic and Social Development" as well as World Bank Open Data.

Table 2. The evaluation system for *FER*, *IER*s, and *IS*.

Project Layer	Index Layer	Unit	Impact
Formal environmental regulation (*FER*)	Industrial wastewater discharge (x1)	metric tons	negative
	Industrial sulfur dioxide emissions (x2)	metric tons	negative
	Industrial particulate matter emissions (x3)	metric tons	negative
	Harmless disposal rate of household waste (x4)	%	positive
	Comprehensive utilization rate of general industrial solid waste (x5)	%	positive
	Centralized treatment rate of sewage treatment plant (x6)	%	positive
Informal environmental regulation (*IER*)	Educational attainment (x7)	/	positive
	Population density (x8)	person/km^2	positive
Upgrading of industrial structure (*IS*)	Rationalization of industrial structure (*RIS*)	/	positive
	Optimization of industrial structure (*OIS*)	/	positive

3.3. Indicator Explanation

(1) Informal environmental regulation (*IER*)

Educational attainment (*x7*) = Number of students in regular higher education institutions/Total population at year-end

Population density (*x8*) = Land area of administrative zone/Total population at year-end

All data used to calculate these 2 micro-indicators of informal environmental regulation are sourced from the "China City Statistical Yearbook".

(2) Rationalization of industrial structure (*RIS*)

Based on the research by Shen et al. (2020), the calculation formula is as follows:

$$RIS = \frac{\sum_i (A_i \times F_i)}{\sqrt{\sum_i A_i^2} \times \sqrt{\sum_i F_i^2}} \quad (1)$$

Note that:

A_i represents the proportion of the real added value of the *i*th industry in real GDP.

F_i represents the proportion of the employed persons in the *i*th industry in the total employed persons.

(3) Optimization of industrial structure (*OIS*)

Based on the previous research, the calculation process is divided into three steps (Fu 2010):

The first step is to use the proportion of the added value of each industry to the regional GDP as three components of a spatial vector, thereby forming a set of three-dimensional vectors.

$$X_0 = (x_{1,0}, x_{2,0}, x_{3,0}) \quad (2)$$

The second step is to separately calculate the angles θ_1, θ_2, and θ_3 between the vectors $X_1 = (1, 0, 0)$, $X_2 = (0, 1, 0)$, and $X_3 = (0, 0, 1)$ as they are arranged from lower to higher levels within the industry.

$$\theta_j = \sum_{k=1}^{3} \sum_{j=1}^{k} \arccos\left(\frac{\sum_{i=1}^{3} (x_{i,j} \times x_{i,0})}{\left(\sum_{i=1}^{3} \left(x_{i,j}^2\right)^{\frac{1}{2}} \times \sum_{i=1}^{3} \left(x_{i,0}^2\right)^{\frac{1}{2}} \right)} \right), j = 1, 2, 3 \quad (3)$$

The third step is to calculate the optimization of industrial structure (*OIS*)

$$OIS = \sum_{k=1}^{3} \sum_{j=1}^{k} \theta_j \quad (4)$$

(4) Control variables

Based on existing research, the control variables that primarily influence the upgrading of the industrial structure include the level of economic development, the level of technological innovation, the level of information development, the level of foreign direct investment, and the level of fixed-asset investment. These variables are, respectively, measured as follows: per capita real gross domestic product (*agdp*), the number of patents (*lnpatent*) (treated by natural logarithm), the ratio of employees in the information transmission, computer services, and the software industry to the total population at the end of the year (*inform*), the ratio of actual foreign direct investment to the regional real GDP (*fdi*), and the ratio of the total actual fixed-asset investment in the whole society to the corresponding regional real GDP (*fixasset*).

3.4. The Measurement of Formal, Informal Environmental Regulation and the Upgrading of Industrial Structure Comprehensive Index

Drawing from the research conducted by Wang et al. (2021), we illustrate the process of calculating all three comprehensive indices (*FER*, *IER*, *IS*) using the formal environmental regulation comprehensive index as an example. To begin, we apply standardization to both positive and negative indicators, with the respective formulas as follows:

$$x_{\eta ij}^{0} = \frac{x_{\eta ij} - x_j^{min}}{x_j^{max} - x_j^{min}} + 0.01 \tag{5}$$

$$x_{\eta ij}^{0} = \frac{x_j^{max} - x_{\eta ij}}{x_j^{max} - x_j^{min}} + 0.01 \tag{6}$$

In the formula, $x_{\eta ij}^{0}$ represents the standardized value of the index j for the i urban agglomeration in η year, $x_{\eta ij}$ represents the original value of the index j for the i urban agglomeration in η year, x_j^{max} and x_j^{min}, respectively, represent the maximum and minimum values of the index j. To prevent zero values, the standardized results were shifted by 0.01.

Then, using the objective weighting method with the information entropy approach to weight the indicators. Denote the weights for the indices of the i urban agglomeration in year η as $w_{\eta ij}$.

Finally, the comprehensive environmental regulation index $Z_{\eta i}$ for the i urban agglomeration in year η is calculated.

$$Z_{\eta i} = \sum_j w_{\eta ij} \times x_{\eta ij}^{0} \tag{7}$$

Note that:

$$\sum_j w_{\eta ij} = 1 \tag{8}$$

3.5. The Measurement of Coupling and Coordination Degree (CCD)

Referring to the research by Deng et al. (2022), we use 2 steps to calculate the coupling and coordination degree of formal and informal environmental regulation.

Firstly, calculate the coupling degree:

$$c = \sqrt{\frac{FER \times IER}{\frac{FER+IER}{2}}} \tag{9}$$

Secondly, calculate the coupling and coordination degree:

$$CCD = \sqrt{c \times (0.5 \times FER + 0.5 \times IER)} \tag{10}$$

In the formula, c represents coupling degree, *CCD* represents coupling and coordination degree, *FER* stands for the comprehensive index of formal environmental regulations, and *IER* represents the comprehensive index of informal environmental regulations. Setting the weights for *FER* and *IER* to be equal at 0.5 indicates that formal environmental regulations and informal environmental regulations hold an equal level of importance.

3.6. Classification Criterion of Coupling and Coordination Degree

Based on the existing classification standards and the calculated results of coupling and coordination degree (Shang and Liu 2021), the coupling and coordination levels are divided into ten grades (Table 3).

Table 3. Classification criterion of coupling and coordination degree.

Range	Stage	Range	Stage
[0.000–0.100]	Extreme disorder	(0.500–0.600]	Reluctance coordination
(0.100–0.200]	Serious disorder	(0.600–0.700]	Primary coordination
(0.200–0.300]	Moderate disorder	(0.700–0.800]	Middle coordination
(0.300–0.400]	Light disorder	(0.800–0.900]	Well coordination
(0.400–0.500]	Near disorder	(0.900–1.000]	High coordination

3.7. Modeling

3.7.1. The Construction of Baseline Regression Model

According to various research findings and preceding text, environmental regulations can influence industrial structure. Environmental regulations can be divided into two dimensions: *FER* (formal environmental regulations) and *IER* (informal environmental regulations). *FER* and *IER* also have a coupled and coordinated relationship. Therefore, the coupled and coordinated development of formal environmental regulations and informal environmental regulations may have an impact on the upgrading of the industrial structure of urban agglomerations. Thus, this paper constructs model (7) to empirically verify the impact of the coupled and coordinated development of formal environmental regulations and informal environmental regulations on the upgrading of the industrial structure of urban agglomerations. The model is set as follows:

$$structure_{it} = \alpha_0 + \alpha_1 d_{it} + \alpha_2 agdp_{it} + \alpha_3 lnpatent_{it} + \alpha_4 inform_{it} + \alpha_5 fdi_{it} + \alpha_6 fixasset_{it} + \varepsilon_{it} \tag{11}$$

Note that, i and t, respectively, represent individual cities (i = 1, 2, . . ., 127) and time (t = 2003, 2004, . . . 2019), ε as error terms.

3.7.2. The Construction of the Panel Threshold Regression Model

The previous analysis indicates that the coordinated development of *FER* and *IER* significantly promotes the upgrading of the industrial structure in urban agglomerations. Hence, whether there is a certain non-linear relationship between the level of *CCD* and the upgrading of the industrial structure in urban agglomerations within different ranges of *FER* and *IER* is worthwhile to be discussed. Based on this, two panel threshold regression models are constructed, with *FER* and *IER* as threshold variables, and the level of *CCD* as the core explanatory variable, to verify the non-linear impact of *CCD* on the upgrading of the industrial structure in urban agglomerations. The two models are set as follows:

$$\begin{aligned} structure_{it} = {} & \lambda_0 + \lambda_1 ccd_{it} \times I(FER_{it} \leq \gamma) + \lambda_2 d_{it} \times I(FER_{it} > \gamma) + \lambda_3 agdp_{it} + \lambda_4 lnpatent_{it} \\ & + \lambda_5 inform_{it} + \lambda_6 fdi_{it} + \lambda_7 fixasset_{it} + \varepsilon_{it} \end{aligned} \tag{12}$$

$$\begin{aligned} structure_{it} = {} & \lambda_0 + \lambda_1 ccd_{it} \times I(IER_{it} \leq \eta) + \lambda_2 d_{it} \times I(IER_{it} > \eta) + \lambda_3 agdp_{it} + \lambda_4 lnpatent_{it} \\ & + \lambda_5 inform_{it} + \lambda_6 fdi_{it} + \lambda_7 fixasset_{it} + \varepsilon_{it} \end{aligned} \tag{13}$$

In these formulas, I represents an indicator function, and γ and η, respectively, represents estimated values for the threshold levels corresponding to *FER* and *IER*.

4. The Calculation Results and Analysis of Coupling and Coordination Degree

4.1. Summarized Analysis of Coupling and Coordination Degree

Table 4 displays the overall formal environmental regulation comprehensive index (*FER*), informal environmental regulation comprehensive index (*IER*), and the coupling coordination degree (*CCD*) in the ten major urban agglomerations. It can be visually observed that during the 17-year period, the coupling and coordination degree between formal and informal environmental regulations shows a consistently improving trend, increasing from 0.508 to 0.621, with a growth rate of 22.09%. However, the overall level of *CCD* is not very high, with it being in reluctance coordination in 2003 and developing into primary coordination after 2010. Meanwhile, both *FER* and *IER* showed an upward trajectory, increasing from 0.735 and 0.113 in 2003 to 0.923 and 0.200 in 2019, with growth rates of 25.58% and 77.80%, respectively. It is evident that *IER* increased significantly more than *FER*. Throughout the entire period, *IER* consistently lagged behind *FER*, and the two exhibited an unbalanced development pattern, which is also in line with the real situation of China's ten major urban agglomeration. Based on Formula (10) in Section 3.4, the *FER* and *IER* are assigned equal weights. A low *IER* in China results in a low *CCD*, preventing the synergistic effect between *FER* and *IER* in China from fully functioning.

Table 4. Overall description of *FER*, *IER* and *CCD*.

Year	*FER*	*IER*	*CCD*	Stage
2003	0.735	0.113	0.508	Reluctance coordination
2004	0.773	0.126	0.528	Reluctance coordination
2005	0.793	0.141	0.545	Reluctance coordination
2006	0.804	0.148	0.554	Reluctance coordination
2007	0.818	0.158	0.566	Reluctance coordination
2008	0.836	0.164	0.575	Reluctance coordination
2009	0.849	0.172	0.584	Reluctance coordination
2010	0.873	0.174	0.590	Reluctance coordination
2011	0.873	0.178	0.594	Reluctance coordination
2012	0.888	0.181	0.598	Reluctance coordination
2013	0.900	0.187	0.604	Primary coordination
2014	0.908	0.189	0.608	Primary coordination
2015	0.912	0.193	0.612	Primary coordination
2016	0.914	0.194	0.613	Primary coordination
2017	0.917	0.196	0.616	Primary coordination
2018	0.916	0.197	0.617	Primary coordination
2019	0.923	0.200	0.621	Primary coordination

The analysis of the reasons is as follows: The beginning of formal environmental regulation in China can be traced back to China's first participation in the international environmental governance conference, the Stockholm Conference on the Human Environment, in 1972. Over the past fifty years, China's environmental regulatory policy system has undergone significant transformations. Environmental legislation started from scratch, evolved from fragmented to systematic, and from pilot projects to nationwide implementation. In practice, the implementation has also transitioned from end-of-pipe control to source control and source prevention, from regional and industry pilot projects to nationwide and all-industry implementation. Formal environmental regulation has made substantial and enduring progress.

Meanwhile, in recent years, with the general improvement of public diathesis and the widespread influence of formal environmental regulations, public environmental awareness has also been enhanced. Ordinary residents, media, and environmental organizations have gradually become involved in environmental protection efforts, becoming important forces in informal environmental regulation. However, the current legal framework for informal environmental regulation is still not perfect, and public environmental concerns remain unresolved, resulting in relatively weak informal environmental regulation. Therefore, it is evident that the imbalanced development of formal and informal environmental regulation is the primary reason for the lower level of coupling and coordination degree.

4.2. Analysis of Coupling and Coordination Degree in Different Urban Agglomerations

Table 5 presents the comprehensive indices of *FER*, *IER*, and *CCD* for various urban agglomerations in 2003 and 2019. According to Table 5, it is evident that *CCD* in the ten major urban agglomerations exhibited an upward trajectory from 2003 to 2019. However, there were significant differences between different urban agglomeration, indicating pronounced polarization.

Table 5. Description of *FER*, *IER* and *CCD* in different urban agglomerations.

Year	Urban Agglomerations	*FER*	*IER*	*CCD*	Stage
2003	Yangtze River Delta	0.848	0.155	0.583	Reluctance coordination
	Pearl River Delta	0.763	0.159	0.558	Reluctance coordination
	Beijing–Tianjin–Hebei	0.633	0.115	0.501	Reluctance coordination
	Shandong Peninsula	0.889	0.141	0.580	Reluctance coordination
	West Taiwan Strait	0.774	0.093	0.480	Near disorder
	Middle Reaches of Yangtze River	0.729	0.093	0.479	Near disorder
	Central Plains	0.793	0.133	0.560	Reluctance coordination
	Guanzhong Plain	0.689	0.117	0.476	Near disorder
	Central and Southern Liaoning	0.635	0.076	0.446	Near disorder
	Chengdu–Chongqing	0.617	0.086	0.466	Near disorder
2019	Yangtze River Delta	0.964	0.237	0.668	Primary coordination
	Pearl River Delta	0.924	0.383	0.737	Middle coordination
	Beijing–Tianjin–Hebei	0.893	0.194	0.628	Primary coordination
	Shandong Peninsula	0.918	0.254	0.674	Primary coordination
	West Taiwan Strait	0.959	0.146	0.575	Reluctance coordination
	Middle Reaches of Yangtze River	0.929	0.173	0.591	Reluctance coordination
	Central Plains	0.930	0.244	0.662	Primary coordination
	Guanzhong Plain	0.915	0.187	0.578	Reluctance coordination
	Central and Southern Liaoning	0.838	0.138	0.563	Reluctance coordination
	Chengdu–Chongqing	0.929	0.149	0.591	Reluctance coordination

The Pearl River Delta, Yangtze River Delta, Shandong Peninsula, and Central Plains urban agglomerations consistently had higher *CCD* compared to other urban agglomerations. Their levels of *CCD* increased from 0.558, 0.583, 0.580, and 0.560 in 2003 to 0.737, 0.668, 0.674, and 0.662 in 2019, respectively. Among these, the Pearl River Delta transitioned from reluctance coordination to a middle coordination, while the other three major urban agglomerations shifted from reluctance coordination to primary coordination. The remaining six urban agglomerations had lower *CCD*. The Beijing–Tianjin–Hebei urban agglomeration increased its *CCD* from 0.501 in 2003 to 0.628 in 2019, moving from a reluctance coordination to primary coordination. The Middle Reaches of Yangtze River urban agglomeration increased its *CCD* from 0.479 in 2003 to 0.591 in 2019, shifting from near disorder type to reluctance coordination type. The West Taiwan Strait, the Central and Southern Liaoning, Guanzhong Plain, and Chengdu–Chongqing urban agglomerations had the lowest *CCD*, increasing from 0.480, 0.446, 0.476, and 0.466 in 2003 to 0.575, 0.563, 0.578, and 0.591 in 2019, transitioning from near disorder to reluctance coordination type.

At the same time, two points can be observed. First, in general, urban agglomerations with higher levels of *CCD* had a lower increment in *CCD*. For instance, among the top four urban agglomerations with the highest level of *CCD*, except for the Pearl River Delta urban agglomeration, the remaining three urban agglomerations had the lowest increases in *CCD*. Urban agglomerations with intermediate levels of *CCD* also had intermediate increases in *CCD*. Among the four urban agglomerations with the lowest *CCD*, apart from the Guanzhong Plain and West Taiwan Straits urban agglomerations, the other urban agglomerations had the highest increases in *CCD*. Second, the comprehensive index of *IER* for all urban agglomerations consistently lagged significantly behind the *FER*. These two showed an imbalanced development trend, with *IER* increasing significantly more than *FER*, consistent with the overall sample.

5. Empirical Study

5.1. Analysis of Baseline Regression Results

Based on the previous analysis of *CCD* (coupling and coordination degree), the ten major urban agglomerations are divided into three groups: Group I consists of the Pearl River Delta, Yangtze River Delta, Shandong Peninsula, and Central Plains urban agglomerations with the highest levels of *CCD*; Group II includes the Beijing–Tianjin–Hebei and Yangtze River Middle Reaches urban agglomerations with intermediate levels of *CCD*; Group III comprises the West Taiwan Strait, the Central and Southern Liaoning, Guanzhong Plain, and Chengdu–Chongqing urban agglomerations with the lowest levels of *CCD*. The impact of *FER* and *IER* on industrial structure upgrading is examined with both the overall ten major urban agglomerations and each group of urban agglomerations. Based on the results of the F-test and Hausman test, a fixed-effects model is ultimately selected to regress the samples. The regression results are shown in Table 6.

Table 6. The result of regression.

	Overall	**Group I**	**Group II**	**Group III**
ccd	0.083 ***	0.197 ***	0.122 ***	0.069 ***
	(7.14)	(4.04)	(4.75)	(3.83)
fixasset	0.008 ***	0.038 ***	0.006 ***	0.006 **
	(5.75)	(9.35)	(2.63)	(2.37)
fdi	0.026	−0.030 *	0.527 ***	−0.133 ***
	(1.43)	(−1.69)	(5.40)	(−3.53)
inform	−0.656 ***	−0.217	−0.621 *	−2.694 ***
	(−4.95)	(−1.59)	(−1.76)	(−8.73)
agdp	−0.004 ***	−0.004 ***	0.001	−0.004 ***
	(−13.01)	(−11.88)	(1.24)	(−5.72)
lnpatent	0.017 ***	0.012 ***	0.014 ***	0.018 ***
	(31.32)	(14.07)	(13.53)	(18.61)
_cons	0.449 ***	0.079 ***	0.630 ***	0.658 ***
	(79.90)	(8.70)	(48.60)	(85.43)
Obs	2159	731	663	765
R-squared	0.997	0.902	0.915	0.936

Note. *t*-statistics in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

For core explanatory variables: The coefficient of *CCD* consistently shows a significant positive effect in both the overall sample and subgroup samples. The value of the coefficient of *CCD* in Group I is sequentially greater than that in Group II and Group III. Based on the formula of the entropy method (please refer to Section 3.4), the result indicates that the growth of *CCD* can significantly promotes the *IS* measured by the rationalization and optimization of industrial structure. Furthermore, the higher the level of *CCD*, the greater the promotional effect.

For control variables:

(1) The coefficient for fixed-asset investment (fixasset) is consistently positive. A possible reason for this might be that under the guidance of a high-quality development strategy, fixed-asset investments tend to flow into high-end emerging industries or are used for the upgrading and transformation of traditional industries. Therefore, it contributes to the upgrading of the industrial structure.

(2) The coefficient of foreign direct investment (fdi) is significantly positive in Group II and significantly negative in Groups I and III. Possible reasons for this analysis are as follows:

Group II includes the Beijing–Tianjin–Hebei and the Middle Reaches of the Yangtze River Delta urban agglomerations. Hebei Province, as an important component of the Beijing–Tianjin–Hebei urban agglomeration, has implemented a policy to accelerate industry transformation in recent years to upgrade its industrial structure, forcing foreign direct investment to shift towards technology-intensive or innovative industries, thereby effectively promoting industrial structure upgrading. The Middle Reaches of the Yangtze River Delta urban agglomeration, as a typical central inland urban agglomeration, developed later. In 2015, the "the Middle Reaches of the Yangtze River Urban Agglomeration Development Plan" proposed to create an inland open cooperation demonstration zone, gradually expanding the scale and improving the quality of foreign direct investment. This helped to prevent foreign investment from entering traditional industries with high pollution, high energy consumption, or low added value, directing it instead towards advanced manufacturing, emerging industries, high-tech, energy conservation, environmental protection, and upgrading projects in traditional industries, thereby promoting industrial structure upgrading.

Cities in Group I are mainly located in developed eastern regions, with relatively high foreign investment levels. However, foreign investment is mainly concentrated in the secondary sector, especially manufacturing, with a lower proportion of investment in other industries. This hinders industrial structure upgrading.

In Group III the Guanzhong and Chengdu–Chongqing urban agglomerations located in the western regions have relatively low levels of foreign direct investment. The Central and Southern Liaoning urban agglomeration, as the largest heavy industry base in China, has relatively weak attraction for foreign capital. Therefore, foreign direct investment has not facilitated industrial transformation and upgrading. Foreign direct investment in the West Taiwan Strait urban agglomeration is mainly concentrated in Fuzhou city. However, Fuzhou's capacity to drive technology progress from foreign direct investment is relatively weak. As a result, the technological progress induced by foreign direct investment has not spilled over effectively to other cities, hindering industrial structure upgrading.

(3) The level of informatization (inform) is significantly or non-significantly negative in groups I, II, and III. Possible reasons for this analysis are as follows: From the construction of information infrastructure, the development of information technology, to the transformation of information technology into actual productivity, a significant amount of time and capital investment is required. However, China started its informatization construction relatively late, had a weak foundation, and the application of informatization in some industrial sectors is still incomplete. Informatization development is still in the stage of accumulating, and its role in upgrading industrial structure has not yet become evident, and it may even be in a stage where returns are less than the investments made.

(4) The level of economic development (agdp) is significantly negative or non-significant. Possible reasons for this may be that Chinese urban agglomerations have focused excessively on the accumulation of quantity during the process of economic development, while neglecting the improvement in quality, such as industrial structure upgrading. As a result, the improvement in the level of economic development has not been able to drive the upgrading of the industrial structure in urban agglomerations.

(5) The level of technological innovation is significantly positive (lnpatent). This indicates that the technological innovation in China's ten major urban agglomerations can, to a certain extent, translate into productivity, thereby driving the upgrading of the industrial structure.

5.2. Analysis of Panel Threshold Regression Model Results

According to Hansen's "bootstrap" method, we sued Stata 16.0 to process our data, the threshold effect test results and panel threshold regression results were obtained through repeated sampling 300 times, as shown in Tables 7 and 8.

Table 7. Testing of threshold effects.

Threshold Variables	Threshold Effects	Threshold Values	F-Statistics	*p*-Values	10% Critical Values	5% Critical Values	1% Critical Values
FER	Single	0.768	14.680	0.343	25.040	33.032	50.244
IER	Single	0.398	50.150	0.030	38.926	44.234	63.983

Table 8. The result of the panel threshold regression model.

	FER as Threshold Variable	*IER* as Threshold Variable
fixasset	0.009 ***	0.009 ***
	(6.47)	(6.40)
fdi	0.021	0.030 *
	(1.14)	(1.67)
inform	−0.648 ***	−0.459 ***
	(−4.83)	(−3.35)
agdp	−0.003 ***	−0.003 ***
	(−11.17)	(−11.51)
lnpatent	0.016 ***	0.016 ***
	(29.75)	(29.43)
Ccd ($FER \leq 0.768$)	0.065 ***	
	(4.56)	
ccd ($FER > 0.768$)	0.074 ***	
	(5.71)	
ccd ($IER \leq 0.398$)		0.114 ***
		(9.52)
ccd ($IER > 0.398$)		0.087 ***
		(7.44)
_cons	0.464 ***	0.443 ***
	(69.62)	(76.90)
Obs	2159	2159
R-squared	0.599	0.605

Note. *t*-statistics in parentheses; *** $p < 0.01$ * $p < 0.1$.

Based on the result of Table 7, we can come to a conclusion that, with the level of *CCD* as the core explanatory variable, when *FER* and *IER* are, respectively, used as threshold variables, *IER* exhibit a single threshold effect with a threshold value of 0.398, while *FER* do not exhibit a threshold effect.

From Table 8, it can be observed that when using *IER* as the threshold variable, if the intensity of *IER* is below the threshold of 0.398, the coefficient for *IER* is significantly positive. This implies that within this range, *CCD* significantly promotes the upgrading of the industrial structure in urban agglomerations. However, if the intensity of *IER* surpasses the threshold of 0.398, the coefficient for *IER* remains significantly positive, but the coefficient value decreases from 0.114 to 0.087. This suggests that prior to reaching the threshold value, the promotion effect of the *CCD* on the upgrading of the industrial structure in urban agglomerations is stronger. In summary, there exists a piecewise linear relationship between the level of *CCD* and the upgrading of the industrial structure in China's 10 major urban agglomerations.

6. Conclusions and Policy Implications

Based on the sample data from 127 cities in ten major urban agglomerations in China during the 17-year period, we used the entropy method to calculate the comprehensive index of *FER*, *IER*, and industrial structure upgrading. A coupling coordination degree model was employed to investigate the characteristics of the coupling and coordinated development of formal and informal environmental regulation in these ten major urban agglomerations. Subsequently, we used fixed-effects models and panel threshold regression models to analyze the impact of *CCD* on the upgrading of industrial structure in city agglomerations.

This paper indicates that the level of *CCD* is on the rise, but there is an imbalance in development among urban agglomerations: the ten major urban agglomerations have transitioned from a state of reluctance coordination to primary coordination. The Pearl River Delta urban agglomerations have progressed from reluctance coordination to middle coordination, while the Yangtze River Delta, Shandong Peninsula, Central Plains, and Beijing–Tianjin–Hebei urban agglomerations have advanced from reluctance coordination to primary coordination. The remaining five urban agglomerations have shifted from near disorder to reluctance coordination. In both overall and grouped samples, the coupling and coordinated development of *FER* and *IER* can significantly promote the upgrading of the industrial structure in urban agglomerations. The higher the level of *CCD*, the greater the promotion effect. Using *IER* as a threshold variable, there is a non-linear relationship between the *CCD* and the upgrading of the industrial structure in urban agglomerations. Currently, in China, the *IER* intensity in the ten major urban agglomerations is relatively reasonable, and the coordinated development of *FER* and *IER* has a significant role in promoting the upgrading of the industrial structure in urban agglomerations. Based on the above conclusions, we can give the following policy implications:

6.1. Improve the Environmental Regulatory Policy System

The formulation and implementation of formal environmental regulation policies should be assessed based on their ability to achieve environmental governance, stimulate enterprise technological innovation, and guide public participation in environmental protection actions. The formulation and implementation of informal environmental regulation policies should also achieve two main purposes: firstly, to enhance public environmental concerns, encourage the public, media, environmental organizations, and others to actively participate in environmental protection; secondly, to gradually standardize and institutionalize, strengthening the supervision of government enforcement actions and corporate production behavior. Currently, the levels of *FER* and *IER* in ten major urban agglomerations are relatively low—the construction of *IER* especially seriously lags behind—which has hindered their coupling and coordinated development. Therefore, in the future, the legal enactment, policy implementation, and policy supervision of *FER* should focus on "prioritize stability while pursuing progress", while the construction of *IER* should proceed gradually. Diverse strategies and methods should be employed to promote the continuous improvement of the environmental regulation system and advance the coordinated development of *FER* and *IER*.

6.2. Formulate Differentiated Industry Development Policies

Different urban agglomerations have different economic foundations, resource advantages, and policy environments. As a result, industry development strategies should also exhibit differences. For instance, Eastern urban agglomerations have significant advantages in terms of geographical location, infrastructure, technological innovation, and talent attraction. They exhibit notable agglomeration effects, spillover effects, and technology leadership effects. These urban agglomerations serve as breeding grounds for new industries and formats such as eco-economy, circular economy, and the digital economy. They also possess convenient conditions for the transformation of traditional polluting industries into high-end, intelligent, and green industries. Therefore, these urban agglomerations should expedite the elimination of outdated production capacity, transform old capacity, nurture new capacity, and promote the high-end and rational development of their industrial structures.

In contrast, urban agglomerations in the central and western regions have relatively underdeveloped economies, scarce high-end resources, limited innovation capabilities, and severely low-end and homogenized industrial structures. They can delve into their own advantageous resources, cultivate industries with comparative advantages, and achieve self-upgrading of their industries. At the same time, it is essential to strengthen connectivity among different urban agglomerations. The central and western urban agglomerations can absorb redundant factors and industries from the eastern urban agglomerations, while the eastern urban agglomerations can provide various types of technology-oriented talent to the central and western urban agglomerations. Ultimately, this will lead to the collective development of these urban agglomerations.

6.3. Emphasize the Synergy, Coordination, and Effectiveness of Various Policies

On the one hand, there should be synergy in the formulation and implementation of different policies within the same urban agglomeration. For instance, environmental regulations should stimulate corporate innovation and drive the upgrading of the industrial structure in the urban agglomeration. Industrial development should reduce investments in highly polluting and energy-intensive industries to minimize environmental pollution and damage. Foreign investment projects should align with the development needs of the urban agglomeration industries, and technological innovation should be translated into productivity to promote the upgrading of the urban agglomeration industrial structure.

On the other hand, various policies in different urban agglomerations should complement each other to promote the overall high-quality development of the urban agglomerations. For example, when formulating industrial development policies in the central and western urban agglomeration, consideration should be given to the responsibility of absorbing redundant industries from the eastern urban agglomerations. In the eastern urban agglomerations, when researching and developing new technologies, consideration should be given to the technological needs of economic development in the central and western regions, and so forth.

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Appendix A

Table A1. List of cities contained in the ten major urban agglomerations.

Location	Urban Agglomeration	List of Cities
Eastern China	Beijing–Tianjin–Hebei	Beijing, Tianjin, Shijiazhuang, Tangshan, Qinhuangdao, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, Xingtai, Handan, Hengshui
	Yangtze River Delta	Shanghai, Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yangzhou, Zhenjiang, Taizhou, Hangzhou, Ningbo, Jiaxing, Huzhou, Shaoxing, Zhoushan, Taizhou, Yancheng, Jinhua
	Pearl River Delta	Guangzhou, Shenzhen, Zhuhai, Foshan, Jiangmen, Zhaoqing, Huizhou, Dongguan, Zhongshan
	West Taiwan Strait	Fuzhou, Xiamen, Zhangzhou, Quanzhou, Putian, Ningde, Longyan, Sanming, Nanping, Wenzhou, Lishui, Quzhou, Shantou
	Shandong Peninsula	Jinan, Qingdao, Yantai, Weifang, Zibo, Dongying, Weihai, Rizhao
	Central and Southern Liaoning	Shenyang, Dalian, Anshan, Fushun, Benxi, Dandong, Liaoyang, Yingkou, Panjin, Tieling, Jinzhou, Fuxin, Huludao
Central China	Middle Reaches of Yangtze River	Wuhan, Huangshi, Ezhou, Huanggang, Xiaogan, Xian'ning, Jingmen, Jingzhou, Jiujiang, Yueyang, Xiangyang, Yichang, Changsha, Changde, Yiyang, Zhuzhou, Xiangtan, Deyang, Loudi, Nanchang, Jingdezhen, Yingtan, Shangrao, Xinyu, Fuzhou, Yichun, Pingxiang
Western China	Central Plains	Zhenzhou, Luoyang, Kaifeng, Xinxiang, Jiaozuo, Xuchang, Pingdingshan, Luohe
	Chengdu–Chongqing	Chongqing, Chengdu, Zigong, Luzhou, Deyang, Mianyang, Suining, Neijiang, Leshan, Nanchong, Meishan, Yibin, Ya'an
	Guanzhong Plain	Xi'an, Xianyang, Baoji, Weinan, Tongchuan

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