BILINGUAL PUBLISHING GROUP

Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

ARTICLE

Capital Matching, Environmental Regulation and Carbon Emission Performance

Shan Yan **, *Wen Zhong*** * **, *Zhiqing Yan***

School of Economics and Management, Jiangxi University of Science and Technology, Ganzhou 341000, China

ABSTRACT

Under the "dual carbon" goal, local governments in China have strategically focused on enhancing capital utilization efficiency and enforcing environmental regulations to improve carbon emission performance. This dual approach targets the intertwined challenges of economic development and environmental protection. Utilizing data from 266 prefecture-level cities in China from 2007 to 2019, this study systematically investigates the effects of capital matching and environmental regulation on carbon emission performance through the spatial Durbin model and the instrumental variable method. The results indicate that both capital matching and environmental regulation significantly enhance carbon emission performance. Capital matching demonstrates positive spatial spillover effects; whereas environmental regulation exhibits negative spatial spillover effects. Furthermore, there are synergistic effects between capital matching and environmental regulation that jointly enhance carbon emission performance. To address potential biases caused by endogenous environmental regulation, the study uses the proportion of environment-related words in provincial government work reports as an instrumental variable for environmental regulation. Additionally, to capture the heterogeneity in the environmental governance willingness and intensity of prefecture-level municipal governments, the study constructs heterogeneous instrumental variables. These variables are derived by multiplying the proportion of a prefecture-level city's total industrial output value to the province's total industrial output value with the proportion of environment-related words in the provincial government work reports. Analyses based on these instrumental variables reveal that endogenous issues in environmental regulation lead to an overestimation of its positive impact on carbon emission performance.

*CORRESPONDING AUTHOR:

Wen Zhong, School of Economics and Management, Jiangxi University of Science and Technology, Ganzhou 341000, China; Email: 15908854450@163.com

ARTICLE INFO

Received: 4 September 2024 | Revised: 13 September 2024 | Accepted: 23 September 2024 | Published Online: 29 October 2024

DOI: https://doi.org/10.30564/jees.v7i1.7206

CITATION

Yan, S., Zhong, W., Yan, Z.Q., 2024. Capital Matching, Environmental Regulation and Carbon Emission Performance. Journal of Environmental & Earth Sciences. 7(1): 29–46. DOI: https://doi.org/10.30564/jees.v7i1.7206

Keywords: Capital Matching; Environmental Regulation; High-Quality Urban Development; Spatial Panel Model; Panel Sill Model

1. Introduction

Development economics posits that development is intrinsically linked to capital accumulation, which is the foundation for initiating social division of labor. However, high-quality economic development, particularly in the context of a low-carbon transformation, necessitates not only quantitative capital accumulation but also qualitative optimization of the capital input structure [1–4]. Fundamental economic transformation hinges on the effective alignment of capital investments, a process heavily dependent on scientific and technological innovation. Such innovation fosters industrial structure transformation and upgrading, improves carbon emission performance, addresses the dual challenges of economic growth and environmental pollution, and promotes low-carbon development. Since the 18th National Congress of the Communist Party of China, environmental policies have been progressively enhanced, leading to significant improvements in China's environmental governance and high-quality environmental development. Despite these advances, environmental pollution continues to impede high-quality economic growth, and the pursuit of the "dual carbon" goals remains an ongoing challenge [5]. In light of the "dual carbon" objectives, critical questions arise: Does the alignment of capital and environmental regulation enhance carbon emission performance? Is there a synergistic effect between these factors? Are there variances based on city size and time periods? The existing literature has not systematically explored these dimensions. Therefore, a comprehensive analysis of the impact of capital alignment and environmental regulation on carbon emission performance is essential. Such an examination would support supply-side structural reforms in capital utilization, strengthen environmental regulation, address the economic-environmental conundrum, and offer new policy perspectives for sustainable development.

In terms of literature review, this paper primarily examines the relationship between capital allocation, environmental regulation, and carbon emission performance. Initially, the determinants of carbon emission performance were explored through the interplay between economic growth and environmental protection. For instance, the well-known Environmental Kuznets Curve (EKC) posits an inverted U-shaped relationship between environmental pollution levels and per capita income [6]. However, some scholars argue for a U-shaped relationship between environmental pollution and economic growth [7]. As globalization progresses, the focus has shifted to the environmental impacts of Foreign Direct Investment (FDI), with hypotheses such as the "pollution haven hypothesis" [8–10] and the "pollution halo hypothesis" [11–13] gaining attention. Recently, Chinese scholars have concentrated on the emission reduction effects of transportation infrastructure. Investments in transport infrastructure are shown to enhance environmental quality, with road area expansions proving particularly effective in reducing pollution [14–21]. Specifically, the development of urban rail transit has been identified as a crucial measure for mitigating congestion and managing environmental concerns, particularly in densely populated cities [22]. Furthermore, the introduction of high-speed rail has significantly decreased urban industrial carbon emissions and has led to positive technological spillovers, aiding industrial carbon emission reductions in small and medium-sized cities along its route [23]. Additionally, literature has examined carbon emission performance from other angles, including environmental regulation [24], fiscal decentralization [25], and economic agglomeration [26]. The growth of cities necessitates substantial resource investment, involving extensive consumption of building materials and municipal infrastructure construction, thereby amplifying the exploitation and utilization of natural resources. Xu et al. demonstrated that the expansion of urban construction land significantly increases energy consumption and greenhouse gas emissions, thereby contributing to climate change [27]. As epicenters of human activity, cities are particularly vulnerable to the effects of climate change. According to Rosenzweig et al., urban areas must contend with the direct impacts of climate change, including floods, droughts, and heatwaves. These phenomena not only detrimentally affect residents' quality of life but also severely test the resilience of urban infrastructure [28]. Recent years have witnessed the proliferation of strategies aimed at mitigating environmental pollution. Mazzi and Dowling suggested that a multifaceted approach, encompassing legislation, economic incentives, and technological innovation, can effectively reduce pollutant emissions and enhance environmental quality [29]. Notably, the integration of green policies and technologies—such as the promotion of renewable energy and the implementation of energy-saving and emission-reduction technologies—has emerged as a pivotal strategy to combat environmental pollution.

The literature on carbon emission performance influenced by capital factors primarily examines the impact of independent capital accumulation on carbon emission performance through high-quality economic development. Low-carbon transformation necessitates innovation, which is inherently talent-driven; talent constitutes the foundation of innovation, and human capital accumulation is pivotal for economic development and industrial structure upgrading [30, 31]. Concurrently, the significance of physical capital accumulation should not be overlooked, as its dynamic integration with technological progress emerges as a principal source of economic growth [32–38]. This sentiment is echoed in studies conducted by foreign scholars [39–41]. While extensive research has been conducted on the externalities of capital accumulation, studies addressing the environmental welfare effects of capital matching are sparse. Moreover, there is a dearth of systematic empirical evidence supporting such research. Most existing studies predominantly employ panel data analysis methods, which tend to disregard the spatial correlation of carbon emission performance, potentially leading to estimation bias.

Existing research consistently indicates that capital accumulation can enhance the quality of economic growth. However, the low-carbon transition necessitates not only high-quality output but also environmentally friendly practices, with the capital matching structure playing a particularly crucial role. Early studies predominantly examined the impact of economic development on environmental pollution [42] and the influence of environmental governance on pollution prevention and control [43], while largely overlooking the effects of environmental governance on carbon peaking and carbon neutrality. In recent years, driven by the "dual carbon" goal, Chinese scholars have increasingly focused on the low-carbon transition facilitated by environmental governance. Under certain conditions, environmental regulation can simultaneously increase the profits of both clean enterprises and polluting enterprises. When the intensity of environmental regulations and the allocation and trading system of emission rights are optimally designed, such regulations can enhance overall social welfare [44]. In more specific terms, market-based environmental regulation has been shown to effectively stimulate innovation, promote green economic growth, and subsequently improves carbon emission performance [45]. Additionally, informal environmental regulation significantly reduces carbon emissions through downsizing, structural optimization, and technological enhancements [46]. However, existing studies have not adequately addressed the perspective of capital matching, nor have they explored the role of environmental regulation in guiding capital matching to improve carbon emission performance.

Given this context, this paper seeks to address the limitations of existing research, which often overlooks the critical role of both capital matching and environmental regulatory guidance in improving carbon emission performance. By integrating these factors into a unified analytical framework, this study not only examines the independent impacts of capital matching and environmental regulation on carbon emission performance but also explores their synergistic effects, as well as the variances related to city size and temporal dimensions. This paper makes a marginal contribution by addressing three key aspects. First, in terms of research content, it explores the synchronous resonance between capital matching and environmental regulation. Capital matching is instrumental in fostering the effective development of environmental regulations, thereby resolving the conflicts between economic advancement and environmental improvement. This synergy is crucial for enhancing economic development potential, optimizing industrial structure, and improving carbon emission performance. The paper constructs a comprehensive analytical framework to investigate the "independent effects" and "synergistic effects" of capital matching and environmental regulation on carbon emission performance, proposing viable strategies to achieve the "dual carbon" goals. Second, regarding research methodology, the study incorporates spatial econometric techniques to account for spatial correlations in the enhancement of carbon emission performance. Additionally, it assesses the nonlinear relationship between capital matching, environmental regulation, and carbon emission performance by employing a panel threshold model for empirical testing. This approach considers the heterogeneity across city scales and temporal dimensions. Third, the research focuses on China's prefecture-level cities, devising instrumental variables that reflect the environmental regulation willingness and intensity of municipal governments. This helps address endogeneity issues inadequately tackled in existing research, thereby enriching and expanding scholarly literature on urban environmental governance and economic development.

The remainder of this paper is structured as follows: Section 2 presents the theoretical analysis and research hypotheses. Section 3 outlines the study design, encompassing the econometric model and data description. Section 4 discusses the measurement results and their implications. Section 5 concludes with policy recommendations, identifies research gaps, and offers an outlook for future studies.

2. Theoretical Analysis and Research Assumptions

2.1. The Impact of Capital Matching on Carbon Performance

This paper mainly draws on the ideas of the Mankiw-Romer-Weil model (MRW model) , which is proposed by Gregory Mankiw, David Romer, David Weil, providing a simple framework for growth regression, by introducing human capital, using three variables of physical capital investment, human capital investment, and population growth rate to establish an extended econometric model, proving the effectiveness of the neoclassical growth rate model (see https://wiki.mbalib.com/wiki/Mankiw-Romer-Weil%E6%A8%A1%E5%9E%8B), and makes adjustments in line with the research purpose of this paper on the basis of the MRW model, forming a carbon emission performance output model covering three major capitals:

$$Y = K\left(t\right)^{\alpha} H\left(t\right)^{\beta} S\left(t\right)^{\gamma} \left[A\left(t\right) L\left(t\right)\right]^{1 - \alpha - \beta - \gamma} \tag{1}$$

In the above formula, Y, K, H, S, A and L represent carbon emission performance output level, physical capital, human capital, social capital, exogenous technology status, and labor supply, respectively, and make the following assumptions: (1) Physical capital, human capital, social capital, exogenous technology and labor supply determine the level of carbon emission performance output. (2) α, β and γ are the factor elasticities corresponding to capital, α > 0, β > 0, γ > 0, and α + β + γ < 1. (3) Exogenous labor and technical level. L (0) and A (0) represent the initial labor force and the initial skill level, respectively, and the growth rate of the two is represented by n and g, respectively, so the model can obtain L(t) = nL(t), A(t) = gA(t), respectively, representing the labor and technology accumulation equations. The savings rates of physical capital, human capital, and social capital are expressed in $d_k d_h$ and d_s, respectively, and assuming that the depreciation rate is the same, they are all δ, so the model obtains the accumulation equation of the three major capitals as follows:

$$\dot{K}\left(t\right) = d_k Y\left(t\right) - \delta K\left(t\right) \tag{2}$$

$$\dot{H}\left(t\right) = d_h Y\left(t\right) - \delta H\left(t\right) \tag{3}$$

$$\dot{S}\left(t\right) = d_s Y\left(t\right) - \delta S\left(t\right) \tag{4}$$

$$\left\{\begin{array}{c} \frac{\partial J}{\partial C} = e^{-\rho t} C^{-\sigma} + \phi = 0 \\ \frac{\partial J}{\partial d_k} = \lambda Y\left(t\right) - \phi Y\left(t\right) = 0 \\ \frac{\partial J}{\partial d_h} = \mu Y\left(t\right) - \phi Y\left(t\right) = 0 \\ \frac{\partial J}{\partial d_s} = \theta Y\left(t\right) - \phi Y\left(t\right) = 0 \\ \frac{\partial J}{\partial K} = \left(\lambda d_k + \mu d_h + \theta d_s\right) \frac{\alpha Y}{K} - \lambda\delta = -\dot{\lambda} \\ \frac{\partial J}{\partial H} = \left(\lambda d_k + \mu d_h + \theta d_s\right) \frac{\alpha Y}{H} - \mu\delta = -\dot{\mu} \\ \frac{\partial J}{\partial S} = \left(\lambda d_k + \mu d_h + \theta d_s\right) \frac{\alpha Y}{S} - \theta\delta = -\dot{\theta} \end{array}\right. \tag{5}$$

Based on the above analysis framework, the total consumption C in the carbon emission performance level is: $C = Y\left(t\right)\left[1 - d_k - d_h - d_s\right]$, Hamiltonian function relation: $J = e^{-\rho t}\left[\frac{C^{1-\sigma}}{1-\sigma}\right] + \lambda\left[d_k Y\left(t\right) - \delta K\left(t\right)\right] + \mu\left[d_h Y\left(t\right) - \delta H\left(t\right)\right] + \theta\left[d_s Y\left(t\right) - \delta S\left(t\right)\right] + \phi Y\left(t\right)\left[1 - d_k - d_h - d_s\right]$, In the context of utility maximization, solving the first-order condition (5) allows us to determine the optimal matching relationship between the three major types of capital and their influence on carbon emission performance. The derived relationship can be expressed as follows, demonstrating the optimal alignment of the three capitals:

$$K : H : S = \alpha : \beta : \gamma \tag{6}$$

Based on Equation (6), it is evident that maximizing the utility of carbon emission performance output necessitates that the three primary capital stock ratios align with their respective factor elasticity ratios. This implies the existence of three optimal capital ratio relationships that must be maintained during the carbon emission performance process. Any deviation from these optimal ratios results in a loss of output efficiency with respect to carbon emission performance. Particularly when capital accumulation reaches significant levels, the coordination and alignment of the capital structure become crucial. From a systemic perspective, the capital required for carbon emission performance should be viewed not as isolated components but as an integrated category within the entire capital system. Focusing solely on the accumulation of a single type of capital disrupts the overall capital system structure, severely diminishing capital operation efficiency. Moreover, due to path dependence, such imbalances can perpetuate a vicious cycle of capital accumulation, ultimately impairing carbon emission performance.

If the model wants to express the optimal proportional relationship of the three major capitals from the perspective of per capita, it needs to build a balanced growth path, as follows:

$$y = \frac{Y}{AL} = k^{\alpha} h^{\beta} s^{\gamma} \tag{7}$$

$$\dot{k} = d_k y - (n + g + \delta)\, k = 0 \tag{8}$$

$$\dot{h} = d_h y - (n + g + \delta)\, h = 0 \tag{9}$$

$$\dot{s} = d_s y - (n + g + \delta)\, s = 0 \tag{10}$$

$$\left\{ \begin{array}{l} \dot{k} = d_k y - (n + g + \delta)\, k^* = 0 \\ \dot{h} = d_h y - (n + g + \delta)\, h^* = 0 \\ \dot{s} = d_s y - (n + g + \delta)\, s^* = 0 \end{array} \right. \tag{11}$$

Among them, k^*, h^* and s^* represent the physical capital, human capital and social capital of effective labor per capita, respectively:

$$\frac{k^*}{h^*} = \frac{d_k}{d_h}, \frac{k^*}{s^*} = \frac{d_k}{d_s}, \frac{h^*}{s^*} = \frac{d_h}{d_s} \tag{12}$$

The above structural formula shows that when the carbon emission performance is in a balanced growth path, the ratio of the three major capitals is equal to the corresponding capital savings rate, that is, $k^* : h^* : s^* = d_k : d_h : d_s$.

According to spatial economics theory, capital matching policies or technologies have positive spatial spillover effects that enhance carbon emission performance in neighboring regions. These spillover routes predominantly occur through regional trade, personnel movement, and knowledge exchange. Based on this theoretical analysis, we propose Research Hypothesis 1.

Hypothesis 1. *Capital alignment positively influences local carbon emission performance. The magnitude of this impact is strongly associated with the degree of capital alignment. Additionally, capital alignment technology exhibits a positive spatial spillover effect, benefiting the carbon emission performance in neighboring regions.*

2.2. The Impact of Environmental Regulation on Carbon Emission Performance

An evaluation of carbon emission performance that neglects environmental factors lacks objectivity and comprehensiveness, potentially misguiding policy formulation. The low-carbon transition focuses on enhancing productivity and growth efficiency, shifting the economic development model towards high efficiency. Regardless of whether environmental governance is integrated into the neoclassical growth model or the endogenous growth model [47, 48], it positively impacts carbon emission performance. According to the "Porter Hypothesis," appropriate environmental regulation can stimulate technological innovation, which effectively enhances green total factor productivity and resource allocation efficiency. As Schumpeter's innovation theory posits, technological innovation is a crucial driver of economic growth [1, 49, 50]. Environmental regulation influences high-quality economic development by improving scale efficiency, driving industrial structure transformation and upgrading, and enhancing resource allocation efficiency. These effects collectively promote low-carbon transformation. Different types of environmental regulation yield varied impacts on the quality of economic growth, with industrial structure transformation and upgrading generally being the primary mediators through which environmental regulation affects low-carbon transition [51]. Therefore, differentiated environmental regulations can significantly improve carbon emission performance. Additionally, focusing on the capital factor structure of regional development, it is evident that environmental regulation impacts the capital input framework. Given the current state of regional industrial structure, intensified environmental regulation prompts a gradual shift from increasing the quantity of factor inputs towards enhancing their quality. This shift actively fosters technological innovation and structural transformation. The enhancement of regional factor input quality is closely tied to the optimization of regional capital allocation. A well-optimized capital structure can sustain long-term regional growth, rendering the traditional high-input development model obsolete. Based on these insights, this paper proposes Hypothesis 2.

Hypothesis 2. *Environmental regulations can enhance carbon emission performance. However, as local environmental regulations become more stringent, polluting enterprises may relocate to neighboring areas, thereby negatively impacting the carbon emission performance of those regions.*

2.3. The Synergy Effect of Capital Matching and Environmental Regulation Affecting Carbon Emission Performance

The quality of capital allocation significantly influences the effectiveness of environmental regulations. This influence manifests through environmental regulations prompting technological innovation, which is a fundamental driver for enhancing carbon emission performance. Generally, the accumulation of physical capital primarily occurs via new investments, encompassing government financial incentives, R&D subsidies, or enterprises' own R&D expenditure. This ensures sufficient R&D capital investment, facilitates the development of new products, and supports the dissemination of new technologies, thereby impacting industrial innovation[52]. Additionally, human capital accumulation enhances technological innovation by improving labor quality, augmenting workers' capabilities, and elevating the efficiency of labor market factor allocation[53]. Furthermore, social capital accumulation boosts the innovation capacity of government entities, corporate organizations, and intermediary institutions through mechanisms such as institutional and management innovation, thereby aiding in organizational innovation[54]. The high-quality development of regional economies fundamentally relies on capital accumulation. Once a substantial level of capital accumulation is achieved, the focus shifts towards leveraging regional innovation synergy through effective capital matching. Capital accumulation is an inherent part of the regional development process. However, to enhance carbon emission performance continuously, it is crucial to achieve a coordinated development of the capital factor structure on the foundation of extensive capital accumulation. Environmental regulation plays a significant role in improving capital matching quality. This is evident through the support and guidance of R&D investment intensity, which enhances capital matching and expands its spatial spillover effects, leading to improved carbon emission performance. In summary, effective capital matching bolsters environmental regulation, enhances economic development quality, and fosters a low-carbon transformation. Conversely, environmental regulations support improved capital matching quality, ensuring the high-quality development of regional economies and facilitating low-carbon transformation. Therefore, a synergy exists between capital matching and environmental regulation, which collectively contributes to better carbon performance. Based on this premise, Research Hypothesis 3 of this paper is proposed:

Hypothesis 3. *Capital alignment will influence the enforcement of environmental regulations. Environmental regulations can drive capital alignment towards technological innovations that benefit the environment. Furthermore, the synergy between capital alignment and environmental regulation will enhance carbon emission performance.*

3. Research Design

3.1. Model Building

3.1.1. Spatial Metrology Model Selection and Setting

The Spatial Durbin Model (SDM) represents a significant advancement in the field of spatial econometrics. It integrates the benefits of both the Spatial Autoregressive Model (SAR) and the Spatial Error Model (SEM), effectively addressing issues related to spatial correlations, including the impacts of random spatial effects. Utilizing the SDM as a foundation, this paper develops a model to investigate both the independent and synergistic effects of capital allocation and environmental regulation on carbon emission performance. The corresponding equation is as follows:

$$\begin{gathered} CEP_{i,t} = \alpha_0 + \rho WCEP_{i,t} + \alpha_1 CM_{i,t} + \\ \alpha_2 ER_{i,t} + \alpha_3 Z_{i,t} + \theta_1 WCM_{i,t} + \theta_2 WER_{i,t} + \\ \theta_3 WZ_{i,t} + \epsilon_{i,t} \end{gathered} \tag{13}$$

$$\begin{gathered}CEP_{i,t}=\alpha_0+\rho WCEP_{i,t}+\alpha_1 CM_{i,t}*\\ ER_{i,t}+\alpha_2 Z_{i,t}+\theta_1 WCM_{i,t}*ER_{i,t}+\\ \theta_2 WZ_{i,t}+\epsilon_{i,t}\end{gathered} \tag{14}$$

Among them, $CEP_{i,t}$, $CM_{i,t}$ and $ER_{i,t}$ are carbon emission performance, capital matching and environmental regulation in the t year of i, respectively, $Z_{i,t}$ is the control variable group, ρ is the spatial autoregressive coefficient, W is the spatial weight matrix, and $\epsilon_{i,t}$ represents the random perturbation term.

According to the "first law of geography", the correlation between regions diminishes with increasing distance, making spatial weight setting a crucial component of spatial model analysis. In addition to geographical distance, capital matching and environmental regulation are influenced by non-geographical factors such as the level of regional economic development. Therefore, this study employs both the geographical distance matrix and the economic geography matrix to comprehensively characterize spatial correlation.

3.1.2. Panel Sill Model Setting

The interplay between capital matching and environmental regulation significantly influences carbon emission performance, potentially exhibiting a "threshold" effect due to their inherent incompatibility. This paper explores this notion by incorporating capital matching and environmental regulation as threshold variables. Zhao, Zhang and Liang [55] empirically tested this hypothesis and developed a panel threshold regression model:

$$\begin{gathered}CEP_{i,t}=\beta_0+\beta_1 CM_{i,t}*I\left\{ER_{i,t}\leq\omega\right\}\\ +\beta_2 CM_{i,t}*I\left\{ER_{i,t}>\omega\right\}+\phi Z_{i,t}+\epsilon_{i,t}\end{gathered} \tag{15}$$

$$\begin{gathered}CEP_{i,t}=\gamma_0+\gamma_1 ER_{i,t}*I\left\{CM_{i,t}\leq\omega\right\}\\ +\gamma_2 ER_{i,t}*I\left\{CM_{i,t}>\omega\right\}+\phi Z_{i,t}+\epsilon_{i,t}\end{gathered} \tag{16}$$

3.2. Variable Measures and Descriptions

3.2.1. The Variable Being Explained

The variable of interest in this study is urban carbon emission performance (CEP), as defined by the research of Ma Dalai, Cheng and Wang [56]. CEP is measured using the SBM-Undesirable model, which incorporates labor, energy, and capital as input factors, with carbon emissions as an undesirable output and GDP as a desirable output. Due to the absence of detailed energy consumption data at the city level, we adopted the approach from prior research [57], utilizing the NPP-VIIRS nighttime light data provided by the NGDC database to downscale carbon emissions for prefecture-level cities in China. This methodology is widely accepted in economic research for its scientific validity. The underlying premise is that brighter nighttime lights indicate more vigorous economic activity, which correlates with higher levels of economic development and energy consumption. The specific steps are as follows: firstly, compile and extract DN values from the nighttime lighting data at both provincial and city levels. Secondly, construct a regression equation between the total nighttime light values and provincial carbon emissions, then estimate the associated parameters. Finally, match and analyze the total DN values at the city level with the estimated parameters to derive carbon emissions for 266 prefecture-level cities from 2007 to 2019.

3.2.2. Explanatory Variables

(1) Capital Matching (CM). This paper examines the process of capital formation and evolutionary development by selecting the three capital elements: physical capital, human capital, and social capital. These elements are interrelated, inherited, and synergistically influence each other. To construct an effective capital matching system, it is essential to choose scientific evaluation indicators, consider the collaborative development mechanisms among the three capitals, and ensure the availability of relevant data. In this study, physical capital is measured by fixed asset investment, estimated using the perpetual inventory method. Human capital is represented by per capita years of education, while social capital is indicated by public service expenditure [58–60]. Furthermore, the study draws on the coupling coordination degree used in physics to construct a model that matches the three major capitals. This model encompasses measurements for two types of capital matching:

$$C_2\left(t\right)=\left\{\frac{u_{1,t}\times u_{2,t}}{\left(\frac{u_{1,t}+u_{2,t}}{2}\right)^2}\right\}^{\frac{1}{2}} \tag{17}$$

$$C_3\left(t\right)=\left\{\frac{u_{1,t}\times u_{2,t}\times u_{3,t}}{\left(\frac{u_{1,t}+u_{2,t}+u_{3,t}}{3}\right)^3}\right\}^{\frac{1}{3}} \tag{18}$$

In the above formula, $u_{1,t},\ u_{2,t}$ and $u_{3,t}$ represent the comprehensive evaluation values of physical capital, human capital and social capital, respectively, and $0\leq C_2\left(t\right)\leq 1$,

$0 \leq C_3(t) \leq 1$, the closer the value is to 1, the better the matching and coordination of each subsystem.

(2) Environmental Regulation (ER) is primarily assessed in this paper through energy consumption metrics, drawing on the methodology of Wang and Lu[61]. Specifically, we employ the GDP-to-Energy ratio (GDP/Energy) to gauge the intensity of environmental regulation: higher values indicate stronger regulatory measures.

3.2.3. Control Variables

A comprehensive review of the literature on factors influencing carbon emission performance reveals that the primary determinants are economic development, population size, and technological advancement. Consequently, control variables pertinent to these factors have been selected for analysis, as depicted in **Table 1**.

Table 1. Description of the control variable.

The Variable Name	Variable Symbol	Calculation Method
Level of economic development	ED	GDP per capita
Regional R&D investment intensity	RTI	R&D investment as a proportion of GDP
Industrial structure	IS	Industrial Structure Rationalization Index
The level of openness to the outside world	FDI	Outward FDI as a share of GDP

3.3. Data Sources

In this study, we selected 266 cities at the prefecture level and above in China, spanning from 2007 to 2019, resulting in 3458 region-years of balanced panel data. The primary data sources include the China Urban Statistical Yearbook, the China Environment Statistical Yearbook, and the statistical yearbooks of various provinces. Due to data unavailability, the regions of Hong Kong, Macao, Taiwan, the Tibet Autonomous Region, and the Inner Mongolia Autonomous Region are not included. For cities with incomplete data, supplementary information was obtained from the EPS global database, CEI database, and Wind database. **Table 2** displays the descriptive statistics for each variable. The findings indicate that carbon emission performance, capital allocation structures, and environmental regulations exhibit characteristics of regional imbalance, underscoring the value and significance of this research.

Table 2. Variable descriptive statistics.

The Variable Type	The Variable Name	Variable Symbol	Mean	Standard Deviation	Min	Max
The variable being explained	Carbon performance	HED	0.466	0.102	0.006	0.531
Explanatory variables	Capital matching	CM	0.526	0.171	0.184	0.624
	Environmental regulation	ER	0.261	0.116	0.277	0.552
Control variables	Level of economic development	ED	10.674	0.625	8.066	12.447
	Regional R&D investment intensity	RTI	9.348	2.036	3.491	12.501
	Industrial structure	IS	0.222	0.099	0.311	0.733
	The level of openness to the outside world	FDI	4.533	1.017	5.124	9.218

Note: Observed value N = 3458.

4. Empirical Results

4.1. Empirical Analysis of Spatial Econometric Models

4.1.1. Spatial Correlation Analysis

Before conducting spatial econometric regression, it is essential to assess the spatial correlation of the study objects. This is typically done using the Moran's I index to investigate the spatial correlation characteristics between variables. This study calculates the global Moran's I index for 266 cities at the prefecture level and above in China from 2007 to

2019, utilizing a geographical distance matrix. The results, presented in **Table 3**, reveal that the Moran's I index values for the core variables were predominantly and significantly positive throughout the observation period. This indicates a substantial spatial correlation among Chinese cities regarding environmental regulation and carbon emission performance, thereby justifying the use of spatial econometric analysis in this paper.

Table 3. Moran'I exponential test results for core variables Static panel model regression results.

Year	CEP	CM	ER
2007	0.226*** (5.830)	0.094* (3.517)	0.019* (1.749)
2010	0.183*** (5.376)	0.086* (3.487)	0.007 (1.496)
2013	0.171*** (5.363)	0.081* (3.480)	0.028* (2.117)
2016	0.167*** (5.286)	0.076** (3.474)	0.033* (2.215)
2019	0.156*** (5.271)	0.066** (3.442)	0.051** (3.404)

Note: () is the Z statistic; ***, **, * indicates that it is significant at the level of 1%, 5%, and 10%, respectively.

4.1.2. Analysis of the Independent Effects of Capital Matching and Environmental Regulation

To verify the robustness of the empirical results, this paper presents various spatial panel model estimations and identifies the fixed-effect model as the optimal choice according to the Hausman test criterion. **Table 4** displays the fixed-effect regression results for the three models under both the geographic distance matrix and the economic geographic matrix. The estimation results of the three models are relatively consistent in terms of significance and direction, despite differences in coefficient magnitudes, thereby demonstrating a certain degree of robustness. Furthermore, the Wald test and R2 value were used to determine the best fitting effect of SDM model, so the subsequent analysis of SDM model was mainly used [62].

Table 4 shows that after controlling for the correlation variables, the spatial autocorrelation coefficient (ρ) is significantly positive at the 1% level, indicating that there is significant spatial autocorrelation in carbon emission performance. In the context of equal conditions, capital matching substantially enhances the carbon emission performance of Chinese cities. Consequently, enterprises can be guided to prioritize R&D investment and technological innovation through science and technology expenditure and R&D subsidies. Such measures can optimize the economic development model, thereby improving both local economic development quality and carbon emission performance. Environmental regulation also exhibits a significantly positive impact on carbon emission performance across both weight matrices. Local governments can utilize environmental regulations to drive industrial structure upgrading and enhance carbon emission performance. Notably, the influence of environmental regulation surpasses that of capital matching, highlighting the paramount role of environmental regulation in fostering better carbon emission outcomes. Nevertheless, there remains untapped potential for improvement in capital matching. Furthermore, the spatial lag coefficient of carbon emission performance is significantly positive in all three models, with the economic distance matrix exerting a greater influence than the geographical distance matrix. This suggests that similarity in economic development levels fosters regional economic interaction, promoting economic agglomeration and facilitating a low-carbon transition. In the field of environmental economics, the estimated coefficient for the spatial spillover effect of capital matching is positive; whereas that for environmental regulation is negative. This suggests that local governments' focus on capital matching enhances the carbon emission performance of neighboring regions. Conversely, stringent environmental regulations compel local polluting enterprises to relocate to nearby areas, thereby adversely affecting carbon emission performance in those neighboring regions.

4.1.3. Analysis of the Synergies between Capital Matching and Environmental Regulation

Capital matching and environmental regulation are closely interrelated, both positively influencing carbon emission performance. This study further examines the synergistic impact of these two factors on carbon emission perfor-

Table 4. Independent effect test results of capital matching and environmental regulation.

Variable	SAR		SEM		SDM	
	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance
CM	0.635** (2.671)	0.596** (2.431)	0.603** (1.965)	0.576* (1.773)	0.649*** (2.298)	0.593*** (2.894)
ER	1.122*** (3.046)	1.123*** (3.017)	1.136*** (3.654)	1.138*** (3.655)	1.157*** (4.763)	1.161*** (4.685)
Control variables	YES	YES	YES	YES	YES	YES
ρ	0.737*** (31.536)	0.842*** (45.681)	0.813*** (42.652)	0.826*** (44.663)	0.698*** (28.998)	0.726*** (33.774)
W*CM	/	/	/	/	0.729* (2.341)	0.773* (2.382)
W*ER	/	/	/	/	–1.468* (–4.781)	–1.511* (–4.023)
Wald-lag	/	/	/	/	76.339*** (15.016)	41.771*** (7.992)
Wald-error	/	/	/	/	88.283*** (19.215)	44.334*** (8.181)
LogL	484.332	489.224	468.653	461.443	501.224	503.202
R^2	0.446	0.418	0.461	0.447	0.442	0.451
The region and time are fixed	YES	YES	YES	YES	YES	YES
Observations	3458	3458	3458	3458	3458	3458

Note: *, **, **** represent significant at the level of 1%, 5% and 10%, respectively; Robust standard errors in parentheses. Same below.

mance through their interaction. The Hausman and Wald test confirms that a fixed-effect Spatial Durbin Model (SDM) is appropriate for this analysis (see **Table 5** for regression results). The results of the synergy effect test, conducted using three different spatial econometric models reveal that the interaction terms between capital matching and environmental regulation are significantly positive at the 1% level. This indicates a synergistic effect wherein environmental regulation compels capital matching to enhance carbon emission performance more effectively. The synergistic impact is significantly greater than the independent effects, demonstrating a beneficial interaction between capital matching and environmental regulation. Emphasizing either capital matching or environmental regulation in isolation fails to maximize improvements in carbon emission performance. It is only through their combined synergy that the most substantial improvements are realized, manifesting in benefits that exceed the sum of their individual effects ("1 + 1 > 2").

4.1.4. Robustness Test

This paper conducts robustness tests through two primary methodologies. First, it substitutes the core explanatory variables following the approach of Ye and Zeng [63], remeasuring the capital structure variables from a residual perspective and performing regression analysis with these newly calculated variables. Second, it employs instrumental variable regression to address potential endogeneity within the model.

In China, environmental regulation predominantly operates through environmental laws, regulations, and administrative directives. The Chinese government's work report acts as a policy guidance document for economic development and environmental management, effectively reflecting the commitment and efforts of local governments in environmental governance. Consequently, this study adopts an instrumental variable construction method inspired by Chen et al. [64]. It employs the proportion of environment-related terms in provincial government work reports as the instrumental variable for environmental regulation. Furthermore, it constructs heterogeneous instrumental variables for county-level environmental regulation by multiplying the proportion of county-level industrial output relative to the provincial total with the proportion of environment-related terms in the provincial government work report.

Based on the robustness test results in **Table 6**, the influence of core explanatory variables on carbon emission performance is consistent in both direction and significance with the benchmark regression. However, applying instrumental variable regression uncovers differences in the regression coefficients. Notably, the independent effect of capital matching is reduced, whereas the effect of environmental regulation is amplified. This indicates that the benchmark model's endogenous issues result in an overestimation of the positive impact of capital matching on carbon emission performance and an underestimation of the influence of local government environmental regulation. Furthermore, the estimated coefficient for the interaction between capital matching and environmental regulation increases, indicating that endogenous factors in environmental regulation lead to an underestimation of their combined effect on carbon emission performance. Additionally, both the spatial autocorrelation coefficient and the spatial spillover effects of capital matching and environmental regulation decrease under instrumental variable regression. The results of the instrumental variable regression underscore the effectiveness of both capital matching and environmental regulations in enhancing carbon emission performance. These findings

Table 5. Test results of synergies between capital matching and environmental regulation.

Variable	SAR		SEM		SDM	
	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance
CM*ER	1.596** (4.791)	1.541** (4.466)	1.589** (4.223)	1.511* (4.194)	1.526*** (3.938)	1.589*** (3.558)
Control variables	YES	YES	YES	YES	YES	YES
ρ	0.746*** (31.781)	0.869*** (45.997)	0.866*** (42.892)	0.848*** (44.843)	0.725*** (29.027)	0.751*** (33.933)
W*CM*ER	/	/	/	/	1.741 (4.902)	1.784* (4.775)
Wald-lag	/	/	/	/	83.896*** (16.778)	47.455*** (8.661)
Wald-error	/	/	/	/	90.289*** (23.771)	48.669*** (10.296)
LogL	470.116	474.661	440.163	445.266	491.233	503.566
R^2	0.502	0.521	0.452	0.479	0.619	0.594

Table 6. Robustness test regression results.

Explanatory Variables	Robustness Test 1: Replace Core Explanatory Variables	Robustness Test 2: Instrumental Variable Regression
CM	0.566*** (2.667)	0.455*** (2.371)
ER	1.154*** (4.657)	1.206*** (4.986)
W*CM	0.771* (2.372)	0.758* (2.119)
W*ER	–1.502* (–4.003)	–1.591* (–4.226)
CM*ER	1.576*** (3.477)	1.611*** (3.596)
ρ	0.716*** (33.725)	0.716*** (33.881)
Control variables	YES	YES
The region and time are fixed	YES	YES
R^2	0.626	0.576

emphasize the critical need for scientifically grounded and effective policies for capital allocation and environmental regulation to facilitate a transition to a low-carbon economy.

4.2. Spatial Association Decomposition Test of Independent Effects and Synergistic Effects

Given the characteristics of the Spatial Durbin Model (SDM), this study decomposes the spatial aggregate effect into direct and indirect effects. Direct effects refer to the local impact of explanatory variables, while indirect effects pertain to the influence of other regions. The total effect, which is the sum of direct and indirect effects, measures the average impact of explanatory variables across all regions (see **Table 7** for results). The regression analysis indicates that, considering independent effects, the three spatial effects of capital matching and environmental regulation are significantly positive. The direct effect exceeds the indirect effect, and the impact of environmental regulation is notably higher than that of capital matching. This suggests that the influence of capital matching on carbon emission performance warrants further investigation. Moreover, the impact of both capital matching and environmental regulation is concentrated locally, with a need for enhanced spillover effects. From the perspective of synergistic effects, the three spatial effects exhibit substantial improvement, exceeding the impact of independent effects significantly. The influence under the economic distance matrix is particularly prominent, highlighting that the synergy between capital matching and environmental regulation is a promising approach for enhancing carbon emission performance in the future.

4.3. Empirical Analysis of Panel Sill Model

To further investigate the mechanism of interaction between the two variables on carbon emission performance, this paper employs capital matching and environmental regulation as threshold variables within a panel threshold model. The objective is to determine whether these variables exhibit a threshold effect on carbon emission performance (refer to **Table 8**). The results indicate that when environmental regulation is utilized as the threshold variable, capital matching evidences a double threshold effect with critical values of 0.793 and 1.586. Conversely, when capital matching is the threshold variable, environmental regulation shows a single threshold effect with a threshold value of 0.703.

In this paper, we continue the regression analysis of the model, incorporating the threshold effect test (refer to **Table 9** for detailed results). The regression outcomes for the capital matching threshold reveal that as capital matching improves, environmental regulation increasingly promotes carbon emission performance. This suggests that capital matching is crucial in harnessing the dividends of environ-

Table 7. Spatial association decomposition test results of independent effects and synergistic effects.

Variable	Direct Effects		Indirect Effects		Total Effect	
	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance	Geographical Distance	Economic Distance
CM	0.644** (1.675)	0.659** (1.799)	0.276* (1.371)	0.263* (1.336)	0.920** (1.886)	0.922** (2.066)
ER	1.155* (2.827)	1.201** (2.944)	0.279* (1.044)	0.291* (1.284)	1.434*** (3.819)	1.492*** (3.903)
CM*ER	1.601** (3.998)	1.646** (4.055)	0.453** (1.433)	0.466** (1.764)	2.054** (4.775)	2.112** (4.9012)
Control variables	YES	YES	YES	YES	YES	YES

Table 8. Threshold effect test results.

Variable		Environmental Regulation Is a Threshold Variable			Capital Matching Is the Threshold Variable		
		Single Threshold	Double Threshold	Three Thresholds	Single Threshold	Double Threshold	Three Thresholds
Single threshold estimate		1.618	1.586		0.692	0.703	
Confidence interval		[0.731, 1.6221]	[1.008, 1.593]		[0.481, 0.795]	[0.485, 0.798]	
Double-threshold estimates			0.793			0.914	
Confidence interval			[0.665, 0.882]			[0.342, 1.036]	
Three threshold estimates				0.973			0.513
Confidence interval				[0.631, 1.122]			[0.342, 0.974]
F statistic		16.176*	14.991**	5.778	14.770**	8.013	7.778
P-value		0.061	0.010	0.303	0.050	0.314	0.163
Number of BSs		400	400	400	400	400	400
Critical value	1%	69.336	20.332	28.005	44.339	45.778	34.132
	5%	44.993	14.887	18.118	31.665	35.661	29.665
	10%	34.006	11.013	14.331	28.001	31.026	26.113

mental regulation, guiding its implementation, enhancing green total factor productivity, sustaining high-quality regional economic growth, and facilitating low-carbon transformation. The threshold regression analysis of environmental regulation indicates that when environmental regulation is at a low level (below 0.793), the impact of capital matching on carbon emission performance is positive but not significant. At this initial stage of environmental regulation, innovation is predominantly characterized by imitation, featuring low investment, rapid results, and high success rates; while the overall economy remains in a state of resource input-driven growth. When environmental regulation enters its second stage (between 0.793 and 1.586), the impact of capital alignment on carbon emission performance is significantly positive. As the intensity of environmental regulation escalates, it compels innovation. When environmental regulation further progresses (beyond 1.586), the effect of forced innovation becomes more pronounced, transitioning innovation into the invention phase, characterized by highest creativity and substantial economic benefits. During this phase, capital alignment plays a significant role in enhancing carbon emission performance. The threshold regression analysis reveals that capital alignment and environmental regulation are interdependent; improving capital alignment facilitates the effective implementation of environmental regulations, thereby enhancing carbon emission performance. Simultaneously, capital alignment requires the support of environmental regulations to become a driving force for low-carbon transformation. The synergistic development of both elements is crucial for optimizing their impact on carbon emission performance.

4.4. Analysis of Heterogeneity

Due to the objective factors associated with varying city sizes or periods, local governments adopt different capital matching policies and environmental regulation systems to promote low-carbon transformation. This paper examines the heterogeneous impact of capital matching and environmental regulation on carbon emission performance based on the previously constructed instrumental variables. The regression results are presented in **Table 10**. According to the city classification standard, the sample cities were divided into large and medium-sized cities and small cities. A 1% increase in capital matching enhances the carbon emission performance of large and medium-sized cities by an average of 0.236%, whereas small cities exhibit an increase of 0.368%. This indicates that the effect of capital matching on carbon emission performance in small cities is significantly

Table 9. Threshold regression results.

Variable	Capital Matching Is the Threshold Variable		Variable	Environmental Regulation Is a Threshold Variable	
	Estimates	t Value		Estimates	t Value
Control variables	YES		Control variables	YES	
ER1	1.237	2.823	CM1	0.522	1.821
ER2	1.291**	3.069	CM2	0.601**	2.011
			CM3	0.681***	2. 722
R^2	0.580			0.611	

greater than in large and medium-sized cities. Additionally, a 1% increase in environmental regulation in small cities enhances carbon emission performance by an average of 0.857%, suggesting that the same environmental regulation system has a greater impact on carbon emission performance in small cities compared to large and medium-sized cities. One possible explanation is that, under the same level of carbon emission performance and willingness for environmental governance, small cities exhibit lower initial carbon emission performance but possess significant potential for improvement. Thus, the marginal effect of improvement is more pronounced. Furthermore, small cities can employ stringent measures, such as administrative orders and accountability mechanisms, to efficiently implement capital matching policies and environmental regulation systems within a shorter timeframe.

The study period is segmented into two distinct phases: the first starting in 2007, marking a significant beginning for China in the rigorous enforcement of environmental regulations, and the second commencing with the 18th National Congress of the Communist Party of China in 2012, reflecting an enhanced commitment and intensity in environmental governance. Since the 18th National Congress, the impact of capital matching on carbon emission performance has remained relatively stable in terms of significance and magnitude. However, environmental regulation has markedly improved carbon emission performance, as evidenced by an increase from 1.211 to 1.225. This improvement can be attributed to the central government's heightened focus on environmental protection and governance post-18th National Congress, manifesting through the introduction of stringent environmental regulations and accountability systems that have bolstered the efficacy and commitment of local governments to environmental governance. Additionally, the regression coefficient for the interaction term between capital matching and environmental regulation has risen from 1.508 to 1.639, indicating a synergistic effect. This suggests that capital matching and environmental regulation mutually reinforce each other, guiding local economies towards green and high-quality development and facilitating a low-carbon transition.

5. Conclusions and Policy Implications

5.1. Conclusions

Based on data from 266 prefecture-level cities and above in China spanning 2007 to 2019, this study analyzes the relationship between capital allocation and carbon emission performance. It utilizes geographic and economic distances as the spatial weight matrices, employing spatial econometric and panel threshold models to examine how capital allocation, environmental regulation, and carbon emission performance interact in multiple dimensions. The main conclusions are as follows:

First, both capital allocation and environmental regulation exhibit significant spatial effects on carbon emission performance. Environmental regulation notably improves local carbon emission performance but has a negative spatial spillover effect on neighboring regions. Conversely, the impact of capital allocation on carbon emission performance is less pronounced than that of environmental regulation, both locally and in surrounding areas, with its positive effects being limited to localized regions. Existing studies have primarily focused on the unilateral impacts of capital investment and environmental regulation on carbon emission performance, without thoroughly investigating their spatial interactions. Therefore, this research addresses a significant gap by exploring these spatial effects.

Second, the interplay between capital allocation and

Table 10. Heterogeneity regression results.

Explanatory Variables	Heterogeneity at City Size		Period Heterogeneity	
	Large and Medium-Sized Cities	Small Cities	2007–2011	2012–2020
CM	0.236*** (1.262)	0.368*** (1.992)	0.443*** (2.361)	0.457*** (2.376)
ER	0.665*** (2.547)	0.857*** (2.643)	1.211*** (4.983)	1.225*** (4.997)
W*CM	0.369* (2.018)	0.478* (2.317)	0.756* (2.115)	0.767* (2.126)
W*ER	–1.542* (–3.025)	–1.465* (–3.116)	–1.585* (–4.214)	–1.595* (–4.227)
CM*ER	1.106*** (3.007)	1.511*** (3.495)	1.507*** (3.563)	1.636*** (3.625)
ρ	0.768*** (33.886)	0.796*** (33.985)	0.704*** (33.866)	0.757*** (33.882)
Control variables	YES	YES	YES	YES
The region and time are fixed	YES	YES	YES	YES
R^2	0.458	0.477	0.491	0.482

environmental regulation is crucial. Focusing solely on either capital or regulation fails to maximize carbon emission performance. It is only when these two factors synergize that substantial improvements in carbon emission performance are achieved, yielding a "1 + 1 > 2" benefit.

Third, while environmental regulation alone has a limited impact on carbon emission performance, its synergy with capital allocation demonstrates a significant positive effect. This underscores the importance of capital matching in enhancing carbon emission performance and leveraging "positive energy" during the implementation of environmental regulations. Additionally, this finding highlights that, under the "dual carbon" goals, both capital matching and environmental regulation are pivotal driving forces for improvement. This paper sheds light on this synergistic relationship, addressing a gap in existing research which has predominantly examined the independent effects of these factors without adequately exploring their combined impact.

Fourth, both capital matching and environmental regulation exhibit threshold effects on carbon emission performance. On the one hand, enhancing capital matching is essential for environmental regulation to effectively promote carbon emission performance. Conversely, capital matching requires the support of environmental regulation to act as a new driving force for improving carbon emission performance. The synergistic effect of both factors is key to optimizing their impact.

Fifth, the influence of capital matching and environmental regulation on the carbon emission performance of small cities is substantially greater than that on large and medium-sized cities. Notably, since the 18th Party Congress, the role of environmental regulation in enhancing carbon emission performance has become increasingly pronounced.

The approach to matching proposed in this paper diverges from existing research, and we further investigate the threshold effects of capital matching and environmental regulation on carbon emission performance. This exploration enhances the policy formulation depth of our findings, while also considering the heterogeneity of China's institutional context and urban scale. Consequently, the research conclusions are more broadly applicable to developing countries.

5.2. Policy Recommendations

To achieve the "dual carbon" goal, the central government must guide local governments in the following key initiatives:

(1) Consideration of Spatial Spillover Effects: Incorporate the spatial spillover effects of capital allocation and environmental regulation on carbon emission performance. Optimize capital structure to ensure the efficient flow of resources. Nationally, the priority should be to devise comprehensive policies that rationally formulate and effectively implement capital allocation strategies tailored to regional development. This includes strengthening laws and regulations related to capital matching, curbing indiscriminate capital investments, and fostering an environment conducive to capital allocation, especially in underdeveloped regions.

(2) Localized Implementation of Capital Matching Policies: To enhance carbon emission efficiency, it is essential to tailor capital matching policies to local conditions. This requires improving regional capital accumulation statistics, developing a robust technical framework for assessing capital

allocation structures, and implementing dynamic monitoring systems to promptly identify and correct discrepancies. Furthermore, policies should exploit the unique characteristics of each region to reinforce and optimize the capital matching structure.

(3) Policy coordination and integrated planning. Develop comprehensive regional development plans that harmonize economic growth objectives with environmental protection aims, ensuring both are coordinated and advanced. Encourage enterprises and research institutions to innovate and implement green technologies to enhance resource efficiency and minimize pollution. Provide financial subsidies and tax incentives to support the research, development, and promotion of green technologies. Introduce market mechanisms, such as emissions trading and carbon trading, to motivate enterprises to proactively reduce pollution. Strengthen environmental information disclosure, embrace public oversight, and foster a strong sense of environmental responsibility among governments and enterprises. Integrate environmental protection into the performance appraisal systems of both governments and enterprises, defining clear responsibilities and goals.

(4) Develop policies to phase out outdated, high-pollution, and high-energy consumption production capacities, thereby fostering the green transformation of traditional industries. Encourage the growth of low-carbon sectors, including information technology, biotechnology, and new energy, to diminish the share of energy-intensive and polluting industries. Increase investment in and utilization of renewable energy sources like solar, wind, and hydropower, while decreasing reliance on high-carbon energy sources such as coal. Promote high-efficiency and energy-saving technologies and equipment to enhance energy efficiency and minimize energy waste.

5.3. Research Deficiencies and Prospects

In comparison to existing research, this paper extends the scope of the research content and methodologies used, yielding conclusions that hold both reference value and practical guiding significance. However, several limitations must be acknowledged. First, while the China Urban Statistical Yearbook has been updated to 2021, inconsistencies in the statistical classification of some data sets mean that urban carbon emissions can only be assessed from 2007 to 2019, precluding an analysis of the latest trends. Second, this study focuses exclusively on China's prefecture-level cities, omitting an examination of counties, thereby limiting the comprehensiveness of the research. Third, urban carbon emissions primarily arise from industrial activities, transportation, and domestic sources. This study primarily utilizes lighting data to reflect domestic carbon emissions, somewhat neglecting industrial emissions. Lastly, the research predominantly considers the behavior of local governments at the city level, overlooking the role of local enterprises and entrepreneurs as key drivers in the market economy. This omission highlights a direction for future research that warrants greater emphasis.

Author Contributions

Conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, supervision, validation, visualization, writing—original draft, writing—review & editing, S.Y.; conceptualization, investigation, project administration, resources, software, visualization, writing—original draft, writing—review & editing, Z.Q.Y.; data curation, formal analysis, formal analysis, methodology, software, supervision, validation, writing—original draft, writing—review & editing, W.Z..

Funding

The authors received no specific funding for this work.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be available on request from the author.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Xu, Z., Zuo, S.J., Ding, S.H., 2021. Carbon peaking and carbon neutrality empower high-quality development: Internal logic and implementation path. Economist. 11, 62–71.

[2] Shao, S., Li, X., 2022. Can market-oriented low-carbon policies promote high-quality economic development? Evidence from the ETS pilot. Social Sciences in Guangdong. 02, 33–45.

[3] Solow, R.M., 1960. Investment and technical progress. Mathematical methods in the social sciences. 1(10), 48–93.

[4] Chen, J.X., 1988. From Nax's "vicious circle of poverty" theory. Shanghai Journal of Economics. 02, 56–59.

[5] Chen, S.Y., Chen, D.K., 2018. Smog pollution, government governance and high-quality economic development. Economic Research Journal. 53(02), 20–34.

[6] Grossman, G., Krueger, A., 1995. Economic growth and the environment. Quarterly Journal of Economics. 110(02), 353–377.

[7] Smulders, S., Bretschger, L., Egli, H., 2011. Economic growth and the diffusion of clean technologies: Explaining Environmental Kuznets Curves. Environmental & Resource Economics. 49(01), 79–99.

[8] Levinson, A., Taylor, S., 2008. Unmasking the pollution heaven effect. International Economic Review. 49(01), 223–254.

[9] Zhao, Z.X., Wang, R., Yan, Y.F., 2013. The trade-embodied carbon and pollution paradise hypothesis: A reinterpretation of the causes of the Environmental Kuznets Curve. Journal of International Trade. 07, 93–101.

[10] Yu, D.H., Zhang, M.Z., 2016. Solving the "heterogeneity problem" and EKR retesting of carbon emissions: A country-based study based on threshold regression. China Industrial Economics. (07), 57–73.

[11] Letchumanan, R., Kodama, F., 2000. Reconciling the conflict between the 'pollution-haven' hypothesis and an emerging trajectory of international technology transfer. Research Policy. 29(01), 59–79.

[12] Zheng, Q., Ran, G.H., Deng, R., et al., 2017. Retesting the environmental effects of FDI in China. China Population, Resources and Environment. 27(04), 78–86.

[13] Huo, W.D., Li, J.F., Chen, R.Y., 2019. Green Development and FDI environmental effects: A data demonstration from "pollution paradise" to "pollution halo." Finance & Economics. 04, 106–119.

[14] Sun, C.W., Luo, Y., Yao, X., 2019. Transport infrastructure and urban air pollution: Empirical evidence from China. Economic Research Journal. 54(08), 136–151.

[15] Yang, S., Jahanger, A., Hossain, M.R., 2023. How effective has the low-carbon city pilot policy been as an environmental intervention in curbing pollution? Evidence from Chinese industrial enterprises. Energy Economics. 118, 106523.

[16] Khan, M., 2023. Shifting gender roles in society and the workplace: Implications for environmental sustainability. Politica. 1(1), 9–25.

[17] Shen, J., Tang, P., Zeng, H., et al., 2023. Does emission trading system reduce mining cities' pollution emissions? A quasi-natural experiment based on Chinese prefecture-level cities. Resources Policy. 81, 103293.

[18] Aqib, M., Zaman, K., 2023. Greening the workforce: The power of investing in human capital. Archives of the Social Sciences: A Journal of Collaborative Memory. 1(1), 31–51.

[19] Niu, S., Luo, X., Yang, T., et al., 2023. Does the low-carbon city pilot policy improve the urban land green use efficiency?—Investigation based on multi-period difference-in-differences model. International Journal of Environmental Research and Public Health. 20(3), 2704.

[20] Zaman, K., 2023. The future of financial support for developing countries: Regional and Islamic monetary funds. Politica. 1(1), 1–8.

[21] Yu, Y., Tang, K., 2023. Does financial inclusion improve energy efficiency? Technological Forecasting and Social Change. 186, 122110.

[22] Liang, R.B., Xi, P.H., 2016. The heterogeneous impact of rail transit on air pollution: An empirical study based on RDID method. China Industrial Economics. 03, 83–98.

[23] Sun, P.B., Ge, L.M., 2021. The road to low carbon: The impact of high-speed rail on industrial carbon emissions. The Journal of World Economy. 44(10), 201–224.

[24] Li, S.S., Ma, Y.Q., 2019. The impact of environmental regulation on the decomposition factors of total factor carbon emission efficiency: Based on the perspective of threshold effect. Journal of Shanxi University of Finance and Economics. 41(02), 50–62.

[25] Tian, J.G., Wang, Y.H., 2018. Fiscal decentralization, local government competition and spatial spillover analysis of carbon emissions. China Population, Resources and Environment. 28(10), 36–44.

[26] He, W.J., Zhang, H.F., Chen, X.C., et al., 2019. An empirical study on population density, industrial agglomeration and carbon emissions in China's provinces: Based on the perspectives of agglomeration economy, congestion effect and spatial effect. Nankai Economic Studies. 02, 207–225.

[27] Liu, Z.H., Xu, J.W., Zhang, C.H., 2022. Scientific and technological innovation, industrial structure upgrading and carbon emission efficiency: PVAR analysis based on interprovincial panel data. Journal of Natural Resources. 37(02), 508–520.

[28] Xu, C., Kohler, T.A., Lenton, T.M., et al., 2018. Future of the human climate niche. Proceedings of the

National Academy of Sciences. 117(21), 11350–11355.
[29] Rosenzweig, C., Solecki, W.D., Hammer, S.A., et al., 2011. Climate change and cities: First assessment report of the urban climate change research network. Cambridge University Press: Cambridge, UK. p. 66.
[30] Mazzi, P.A., Dowling, M.S., 1993. Environmental regulation and economic efficiency: Exploring the linkages. Environmental and Resource Economics. 3(1), 27–41.
[31] Zhao, Z.G., Lv, B.X., Guo, Q.W., et al., 2007. The dynamic integration of capital accumulation and technological progress: A typical fact of China's economic growth. Economic Research Journal. (11), 18–31.
[32] Wu, J.G., Ye, A.Z., 2016. The spatial shock effects of capital accumulation, economic growth and energy emissions: A study based on SSpVAR model. Science of Science and Management of S. & T. 37(05), 24–33.
[33] Zhang, M., Tan, S., Pan, Z., et al., 2022. The spatial spillover effect and nonlinear relationship analysis between land resource misallocation and environmental pollution: Evidence from China. Journal of Environmental Management. 321, 115873. DOI: https://doi.org/10.1016/j.jenvman.2022.115873
[34] Wang, A., Han, Y., Zhang, M., et al., 2024. Impact of seasonal global land surface temperature (LST) change on gross primary production (GPP) in the early 21st century. Sustainable Cities and Society. 110, 105572. DOI: https://doi.org/10.1016/j.scs.2024.105572
[35] Xu, C., Huang, G., Zhang, M., 2024. Comparative analysis of the seasonal driving factors of the urban heat environment using machine learning: Evidence from the Wuhan urban agglomeration, China, 2020. Atmosphere. 15(6), 671. DOI: https://doi.org/10.3390/atmos15060671
[36] Zhang, M., Tan, S., Zhang, C., et al., 2024. Machine learning in modelling the urban thermal field variance index and assessing the impacts of urban land expansion on seasonal thermal environment. Sustainable Cities and Society. 106, 105345. DOI: https://doi.org/10.1016/j.scs.2024.105345
[37] Zhang, M., Tan, S., Zhang, Y., et al., 2022. Does land transfer promote the development of new-type urbanization? New evidence from urban agglomerations in the middle reaches of the Yangtze River. Ecological Indicators. 136, 108705. DOI: https://doi.org/10.1016/j.ecolind.2022.108705
[38] Du, Y.X., Sun, H., Wan, X., 2021. Tripartite supervision mechanism and evolutionary strategies for marine ranching ecological security: Policy tools perspective. Regional Studies in Marine Science. 50, 102125. DOI: https://doi.org/10.1016/j.rsma.2021.102125
[39] Batabyal, A.A., Nijkamp, P., 2013. Human capital use, innovation, patent protection, and economic growth in multiple regions. Economics of Innovation and New Technology. 22(2), 113–126.
[40] Guillaumont, P., McGillivray, M., Wagner, L., 2015. Performance assessment, vulnerability, human capital, and the allocation of aid among developing countries. World Development. 48(6), 366–373.
[41] Teixeira, A.A.C., Queirós, A.S.S., 2016. Economic growth, human capital and structural change: A dynamic panel data analysis. Research Policy. 45(8), 1636–1648.
[42] Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. The Quarterly Journal of Economics. 110(2), 353–377.
[43] Shen, P., Jin, G., Fang, X., 2017. Have environmental regulations caused pollution to shift nearby? Economic Research Journal. 52(05), 44–59.
[44] Deng, Z.Q., Gao, T.F., Pang, R.Z., et al., 2022. Research on the phenomenon of "passive collusion" of enterprises: Analysis of the welfare effect of environmental regulation under the goal of "dual carbon." China Industrial Economics. 07, 122–140.
[45] Liao, W.L., Dong, X.K., Weng, M., et al., 2020. Economic effects of market-based environmental regulation: Emissions trading, green innovation and green economic growth. China Soft Science. 06, 159–173.
[46] Zhang, H., Fen, F., 2020. Whether informal environmental regulation can reduce carbon emissions?—Comes from quasi-natural experiments in environmental information disclosure. Research on Economics and Management. 41(08), 62–80.
[47] Chichilnisky, G., 1994. North-South trade and the global environment. American Economic Review. 84(4), 851–874.
[48] Grimaud, A., Rouge, L., 2005. Polluting non-renewable resources, innovation and growth: Welfare and environmental policy. Resource and Energy Economics. 27(2), 109–128.
[49] Shi, H.P., Yi, M.L., 2020. Research on the impact of environmental regulation on high-quality development and spatial spillover effect. Inquiry into Economic Issues. (05), 160–175.
[50] Shangguan, X.M., Ge, B.H., 2020. Scientific and technological innovation, environmental regulation and high-quality economic development: Empirical evidence from 278 cities at the prefecture level and above in China. China Population, Resources and Environment. 30(06), 95–104.
[51] Fan, Q.Q., Cu, C.J., Gao J.N., 2020. The impact of environmental regulation and industrial structure upgrading on high-quality economic development. China Population, Resources and Environment. 30(06), 84–94.
[52] Liang, S.L., Liang, Q.L., 2015. Comparison of the difference between the type of physical capital and the regional industrial innovation effect in China. Industrial Economic Review. 6(05), 5–19.
[53] Wang, H., Huang, X.H., Chen, H.Y., et al., 2020. How human capital matching affects firm markup rates: Theoretical mechanisms and empirical evidence. Finance

& Trade Economics. 41(01), 110–128.

[54] Xin, F.D., 2009. On the coordinated development of knowledge innovation, institutional innovation, technological innovation and management innovation. Ningxia Social Sciences. (03), 47–50.

[55] Zhao, T., Zhang, Z., Liang, S.K., 2020. Digital economy, entrepreneurship, and high-quality economic development: Empirical evidence from urban China. Journal of Management World. 36(10), 65–76.

[56] Ma, D.L., Cheng, Z.C., Wang, L., 2015. Spatial measurement of China's interprovincial carbon emission efficiency. China Population, Resources and Environment. 25(01), 67–77.

[57] Chen, H., Zhang, X., Wu, R., et al., 2020. Revisiting the environmental Kuznets curve for city-level CO2 emissions: Based on corrected NPP-VIIRS nighttime light data in China. Journal of Cleaner Production. 268(06), 121575–121609.

[58] Qian, X.Y., Xu, W.Y., Wang, Q.S., 2009. An empirical study on the difference between the total capital level of various provinces and cities in China. Economic Geography. 29(07), 1064–1069.

[59] Cai, Z., Wang, D.W., 1999. China's economic growth sustainability and labor contribution. Economic Research Journal. 10, 62–68.

[60] Wang, J.X., Wang, S.Y., 2016. Whether social capital and technological innovation can break the "resource curse"? — Based on the research of panel threshold effect. Economic Research Journal. 51(12), 76–89.

[61] Wang, Q.Y., Lu, F.Z., 2018. Whether environmental regulation can promote China's high-quality economic development?—An empirical test based on interprovincial panel data. Journal of Zhengzhou University (Philosophy and Social Sciences Edition). 51(06), 64–70.

[62] Li, X., Deng, F., 2019. Scientific and technological innovation, industrial structure upgrading and economic growth. Science Research Management. 40(03), 84–93.

[63] Ye, D.Q., Zeng, F.Q., 2019. "Financial structure-technology level" Matching degree and economic development: A study based on cross-border panel data. Studies of International Finance. 01, 28–37.

[64] Chen, Z., Kahn, M.E., Liu, Y., et al., 2018. The consequences of spatially differentiated water pollution regulation in China. Journal of Environmental Economics and Management. 88(08), 468–485.