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How Environmental Regulation, Digital Development and Technological Innovation Affect China's Green Economy Performance: Evidence from Dynamic Thresholds and System GMM Panel Data Approaches

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Abstract: Based on the background of China's "carbon neutral" policy and the booming digitalization, how does environmental regulation affect green economy performance? The existing literature has studied the impact of energy consumption on green economic performance. However, the literature has ignored the impact of carbon dioxide emissions on China's green economy performance. In this regard, this research uses the non-radial distance function (NDDF) to calculate the green economic performance of China's prefecture-level cities, and uses the dynamic panel threshold model and the systematic GMM method to study the nonlinear impacts and mechanisms of environmental regulation, digital development, technological innovation, and industrial structure upgrade on green economic performance. The panel data set contains 228 Chinese cities from 2003 to 2019. The following findings are established: first, after adding carbon dioxide emissions to China's green economy performance, the environmental performance was reduced, and the green economy performance was also reduced. Second, the impact of environmental regulations on green economic performance has a double-threshold effect, with threshold values of −0.267 and 3.602, and this double-threshold effect has temporal and regional heterogeneity. Third, environmental regulations of different intensities have a single-threshold effect between digital development, technological innovation, and industrial structure upgrade, with threshold values of 2.955, 3.957, and 2.249, respectively. Fourth, digital development, technological innovation, and industrial structure upgrade promote green economic performance. Fifth, environmental regulation acts on green economic performance through the transmission of digitalization, technological innovation, and industrial structure upgrade. Based on these empirical findings, this research suggests that Chinese local governments should appropriately increase the intensity of environmental regulations, strengthen the digital application and technological innovation, and promote the upgrading of industrial structure to achieve the improvement of urban green economic performance.

Keywords: environmental regulations; green economic performance; digital development; dynamic panel threshold model; system GMM

1. Introduction

According to data released by the National Bureau of Statistics of China, China's GDP increased from CNY 367.9 billion in 1978 to CYN 101,598.62 billion in 2020, and China's economic growth has reached 275%, making it the second-largest economy in the world.

In addition, China's per capita GDP increased from CNY 385 in 1978 to CNY 71,659 in 2020, an increase of 185 times. Such rapid economic growth is due to China's economic development model. China's early economic development model was mainly based on the industrial economy, adopting an "extensive" economic growth model of factor input and scale expansion at the expense of the environment, causing environmental problems such as land desertification, air pollution, and water pollution. According to a statistical survey conducted by the Ministry of Ecology and Environment in China in 2020, 202 of the 337 cities across the country have reached environmental air quality standards, 135 cities have exceeded environmental air quality standards, accounting for 40.1% of the national cities, and the proportion of days with environmental air pollution in 337 cities has reached 13%, corresponding to a rank of 120/180 in the World Environmental Performance Index ranking. In addition, China's annual carbon dioxide emissions are 1.0357 billion tons, making it one of the most severely polluted countries in the world. It can be seen that no matter from which perspective, China's total environmental pollutant emissions are high, and the major pollution emissions exceed the environmental capacity, resulting in increasingly serious environmental pollution. This economic growth at the expense of the environment is contrary to the concept of coordinated economic and environmental development advocated by China. Therefore, abandoning this economic development model based on wasting resources and polluting the environment, following instead the concept of green and low-carbon development, and promoting the high-quality, green, and sustainable development of the Chinese economy has become an indispensable step for China's economic development. As a brand-new social development model, sustainable development not only covers all aspects of human life and production, but also requires people to live in harmony with nature. Correctly handling the relationship between the environment and the economy is an essential step in implementing sustainable development strategies.

To break the "one or the other" situation between the environment and the economy, and to coordinate environmental protection and high-quality economic development, environmental regulations are a key core factor. In recent years, the Communist Party and the government of China have issued a series of environmental protection policies. For example, the 18th National Congress of the Communist Party of China issued the "Overall Plan for the Reform of Ecological Civilization System", the "13th Five-Year Plan for Ecological Environment Protection" was issued in 2016, and the "carbon peak and carbon neutral" policy was proposed in 2021. It can be seen that the Chinese Communist Party and the government's emphasis on environmental protection has reached an unprecedented new height. Regarding the green economic system as a new development goal, taking into account both economic growth and the ecological environment, and realizing economic green development are inevitable trends in the development of the Chinese economy and the global economy in the new era.

Green economic performance is a concept with rich connotations. It not only considers the transformation of economic growth drivers such as energy conservation and emission reduction, technological innovation, and industrial transformation, it also involves the effects of economic growth. It pursues sustainable growth of the environment, resources, and economy. Carbon peaking and carbon neutrality are closely related to socioeconomic development. In the context of today's increasingly serious environmental problems, the question is how to balance the relationship between carbon peaking and carbon neutrality and the economic recovery of various countries, while ensuring the stable operation and growth of the national economy and vigorously promoting the innovation and development of the green energy revolution. At the same time, carbon emission reductions will also be closely related to the transformation of the economy and society to a green cycle, as well as entailing changes in production and lifestyle. Achieving carbon peaking and carbon neutrality is an inherent requirement for China's comprehensive green transformation and the development of a green and low-carbon economy.

Based on the above background, this paper aims to analyze the impact of environmental regulation on green economic performance, and the mediating roles of digitalization, technological innovation, and industrial structure upgrade in environmental regulation and green economic performance. It explores how different cities display significant differences in terms of development status, how in-depth research can be conducted on the impact on high-quality economic growth of environmental governance in different regions according to their own conditions, and then different environmental governance intensities can be adopted according to the development characteristics of each region. This research provides a policy basis for each region to formulate a systematic, comprehensive, and differentiated sustainable development strategy according to their own realities. This study firstly considers the impact of the latest environmental protection policy of "carbon peak and carbon neutrality", then measures the performance of China's green economy and analyzes its development status and evolutionary laws. Second, this research analyzes the heterogeneity of the relationship between environmental regulations and China's green economy performance. Finally, this study considers the impact of digitalization, technological innovation, and industrial structure upgrade to analyze the pathways and effects of environmental regulations on China's green economic growth. This not only helps to objectively evaluate the status quo of China's economic development, it also helps to optimize environmental regulations, digital development, technological innovation, and industrial structure upgrade to achieve the goal of a win–win situation for China's economy and the environment.

2. Theory and Hypotheses

Grossman and Kruger [1] divided the influence channels between economic development and environmental pollution into structural effects, scale effects, and technological effects. Digitalization is a systematic and comprehensive transformation of the strategy, structure, operation, and other aspects of various entities such as enterprises and governments by using the new generation of information technologies such as the Internet, big data, blockchain, and artificial intelligence. It emphasizes the reshaping of the entire organization by digital technology, enabling model innovation and business breakthroughs, and can lead to growth on the economic scale. Technological innovation includes information technology innovation. As an important technological innovation, the digital economy itself often requires a lot of manpower and material resources for R&D and design, as well as the transformation and upgrading of traditional industries. Based on this, this study analyzes the scale effect of digitalization, the technological effect of technological innovation, and the structural effect of industrial structure upgrade as the influence mechanism of environmental regulation and green economic performance. Figure 1 is a hypothetical conceptual model.

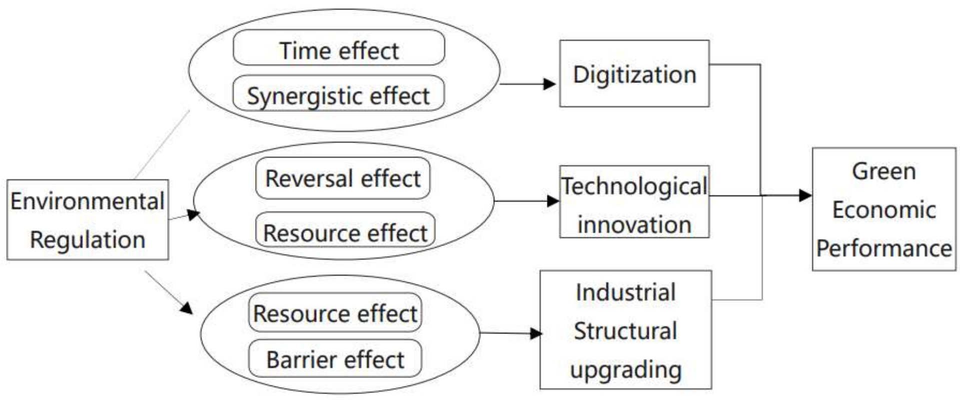

Figure 1. Hypothetical conceptual model.

2.1. Nexus between Environmental Regulation and Green Economy Performance

China's early government performance evaluation mechanism mainly focused on economic growth. To promote local economic growth, local governments in China obtained opportunities for capital promotion through investment promotion, and at the expense of the environment; they placed environmental protection behind economic development and reduced the intensity of environmental regulations to reduce the environmental governance costs of local companies [2,3]. The local governments adopted a competitive strategy of "race to the below" with respect to environmental governance, which has led to increasingly severe environmental pollution problems and has had a negative impact on the performance of the local green economy [4]. On the other hand, with the introduction of China's green development concept, environmental protection and environmental governance have received the attention of the Chinese central government, and environmental protection indicators have been included in the government's performance evaluation [5]. Local governments are paying increasing attention to environmental protection and regard environmental protection and economic growth as equally important. The government has increased the intensity of environmental regulations and increased supervision over corporate environmental governance. Chinese companies have responded to high-strength environmental regulations through transfer, upgrade, and transformation, as well as the reduction of undesired outputs. Local governments in China are now adopting a competitive strategy of "race to the top" to improve environmental pollution, which has had a positive impact in the performance of the local green economy [6,7]. Based on the above analysis, this study proposes Hypothesis 1.

Hypothesis 1 (H1). *Environmental regulations of different intensities have a nonlinear relationship with China's green economy performance.*

2.2. Nexus between Environmental Regulation, Digital Development, and Green Economy Performance

Environmental regulations of different strengths have different strengths for digital applications. First, from the perspective of the time effect of digitalization, in the early stage of China's economic development, the intensity of environmental regulations was weak, and the digital industry had not yet developed. The Chinese government rarely applied digital environmental governance systems in the initial implementation of environmental regulations, and digital applications did not include a number of different fields. Instead, the gradual development of digitalization stimulated economic growth. The growth of the economic scale increased undesired output and environmental pollutants, leading to increased pressure on environmental governance and adversely affecting the performance of the urban green economy.

Second, from the perspective of the synergistic effect of digitalization, when China's economic development entered a period of high-quality development, the intensity of environmental regulations was strong, and the digital industry gradually developed. The government increased the application of the digital environmental governance system in the implementation of environmental regulations. Digitalization enhances the implementation of government environmental regulations with respect to information communication, supervision, and corruption in environmental governance. First, the construction of a digital platform can provide the Chinese government with a more real-time and transparent communication platform. Pollution control issues and public appeals in various regions of China can be reflected through diversified digital channels (such as online communities, emails, etc.). In addition, digitalization can reduce the cost of information communication and improve the efficiency of communication among individuals, enterprises, and governments. It will help governments at various levels in China to formulate more detailed, scientific, and reasonable governance policies [8], improve the implementation of government environmental regulations, and promote the impact of environmental regulations on green economic performance. Second, digital applications can provide the Chinese government and the public with a digital supervision platform, making the government's supervision of the pollution sources in prefecture-level cities and the implementation of environmental protection of enterprises more intelligent, transparent, and efficient. It can reduce the direct information asymmetry between individuals, enterprises, and the government, improve the quality of supervision, implement environmental regulations and policies for the Chinese government, and improve China's green economic performance to an important degree [9]. Third, digital construction can reduce corruption in the implementation of environmental regulations by the Chinese government. Due to the provision of a more transparent, convenient, and real-time digital platform, it is easier for the public to expose government environmental corruption, improve the efficiency of direct enforcement of environmental regulations, and strengthen the impact of environmental regulations on China's green economy performance [10]. Based on the previous theoretical analysis, this study proposes the following hypotheses:

Hypothesis 2 (H2a). *Environmental regulations of different intensities have a nonlinear relationship with digitalization.*

Hypothesis 2 (H2b). *Environmental regulation acts on green economic performance through digitalization.*

2.3. Nexus between Environmental Regulation, Technological Innovation, and Green Economy Performance

The main market tools for environmental regulation are the payment of pollutant discharge fees and the receipt of environmental protection subsidies. First, on the one hand, from the perspective of the "resource effect" of the payment of sewage charges, the neoclassical school believes that in the short term, environmental regulations will increase the compliance cost of enterprises. Enterprises need to pay pollutant discharge fees for the pollutants generated in their production activities, increasing the environmental capital cost of the enterprise and squeezing out the financial resources of the enterprise for technological innovation. However, it often takes a long time for the technological innovation resulting from R&D investment into technological output to be reflected in energy-saving and emission-reduction effects and enterprise green performance [11,12]. Therefore, under the pressure of the payment of sewage charges and short-term capital flow, the externalized impact of environmental regulations will be transformed into an internalized pressure of enterprises, forcing enterprises to abandon technological innovation and reduce the efficiency of enterprise resource allocation, which is not conducive to the improvement of green economic performance. On the other hand, from the perspective of the "crowding-out effect" of environmental protection subsidies, the Chinese government stipulates that environmental protection subsidies can only be used for key pollution control and comprehensive environmental management. Although they reduce companies' short-term environmental costs, subsidies cannot be used for other purposes, squeezing out the company's resources for green technological innovation [13]. Chinese companies are able to meet the government's environmental protection requirements through the use of environmental protection subsidies, and they therefore have little incentive to invest in green technological innovation, thereby reducing corporate environmental and economic benefits and reducing green economic performance.

Second, on the one hand, from the perspective of the "reverse effect" of sewage charges, over time, appropriate environmental regulations will force enterprises to carry out technological innovation [14,15]. The technological achievements in the production and operation activities of an enterprise will be used to improve the production efficiency and competitiveness of the enterprise, forming compensatory income that exceeds the cost of environmental regulations. Companies will strengthen their technological innovation [16], creating a green competitive advantage, and improving corporate green economic performance. On the other hand, from the perspective of the "resource effect" of environmental protection subsidies, the direct subsidies provided in line with the Chinese government's environmental regulations will provide a source of funds for enterprises' technological innovation. This will reduce the cost of technological innovation, alleviate the temporary resource constraints faced by enterprises [17], direct more resources towards technological innovation, promoting green economic performance. Therefore, this research proposes the following hypotheses:

Hypothesis 3 (H3a). *Environmental regulations of different intensities have a nonlinear relationship with technological innovation.*

Hypothesis 3 (H3b). *Environmental regulation acts on green economic performance through technological innovation.*

2.4. Nexus between Environmental Regulation, Industrial Structural Upgrade, and Green Economy Performance

In the early stage of economic development, the performance evaluation of the Chinese government focused on economic growth, and the intensity of environmental regulations was relatively weak. To achieve rapid industrialization, China gave priority to the development of heavy industry [18]. On the one hand, from the perspective of the "resource effect" of environmental regulations, with the acceleration of China's industrialization, more and more resources have been optimally allocated or even excessively opened for use. This has led to a sharp increase in China's industrial pollutants, and the environmental bearing capacity cannot bear the excessive consumption of resources. Moreover, the speed with which resources are being opened and used far exceeds the speed of resource regeneration [19], greatly increasing environmental pollution and negatively affecting urban green economic performance. On the other hand, from the perspective of the "barrier effect" of environmental regulations, as the economy enters a period of high-quality development, the Chinese government has added environmental protection indicators to its evaluation of performance. The strengthening of environmental regulations will raise the barriers to entry for polluting industries, bringing about a "barrier effect". Environmental regulation promotes upgrading the industrial structure through resource allocation and survival of the fittest [20]. In addition, it can change corporate capital investment, allowing companies to increase investment in clean production equipment, promote the development of the clean energy industry, reduce high-pollution and high-energy-consumption industries, and promote green economic performance [21,22]. On the basis of the theoretical analysis above, this article proposes the following hypotheses:

Hypothesis 4 (H4a). *Environmental regulations of different intensities have a nonlinear relationship with the upgrading of industrial structures.*

Hypothesis 4 (H4b). *Environmental regulation acts on green economic performance through the upgrading of industrial structures.*

3. Methodology

3.1. Model Settings

3.1.1. Dynamic Panel Double-Threshold Model

Different intensities of environmental regulations may lead to different degrees of impact on green economic performance. To test the nonlinear impact of environmental regulations on China's green economic performance, this study refers to the panel threshold model proposed by Hansen [23]. In addition, considering the lagging effect of green economic performance, the lagging period of green economic performance is incorporated into the model to build a dynamic panel threshold model. Before building the model, first the dynamic panel threshold model is estimated in order to determine the number of thresholds and threshold values. The specific test results are shown in Table 1. According to the results in Table 1, the F statistics of the single-threshold test and the double-threshold test were significant at the 1% significance level, while the F statistic for three thresholds was not significant. This shows that environmental regulations have a double-threshold effect on green economic performance; therefore, the dynamic panel threshold model constructed in this paper is as follows:

$$\begin{aligned} lnGEP_{i,t} = \mu_i + \beta_i lnX_{i,t} + \lambda_1 lnGEP_{i,t-1}\cdot I(lnER_{i,t} \le \gamma_1) + \lambda_2 lnGEP_{i,t-1}\cdot I(\gamma_1 \le lnER_{i,t} \le \gamma_2) + \lambda_3 lnGEP_{i,t-1} \\ \cdot I(lnER_{i,t} \ge \gamma_2) + \alpha_1 lnER_{i,t}\cdot I(lnER_{i,t} \le \gamma_1) + \alpha_2 lnER_{i,t}\cdot I(\gamma_1 \le lnER_{i,t} \le \gamma_2) + \alpha_3 lnER_{i,t}\cdot I(lnER_{i,t} \ge \gamma_2) + \varepsilon_{i,t} \end{aligned} \quad (1)$$

Table 1. Threshold effect test.

	Threshold Value	F Value	*p* Value	10% Critical Value	5% Critical Value
Single-threshold test	−0.2665 ***	68.11	0.000	20.82	25.07
Double-threshold test	3.6020 ***	31.27	0.000	17.99	20.33
Triple-threshold test	−0.5798	5.03	0.9167	15.43	17.78

Note: *** indicates that the regression coefficient is significant at the level of 1%.

In Formula (1), $lnGEP_{i,t}$ represents green economic performance, $lnER_{i,t}$ represents environmental regulation, $lnX_{i,t}$ represents the collection of control variables, $I(\cdot)$ is the indicative function. When $lnER_{i,t} \le \gamma_1$, $I(lnER_{i,t} \le \gamma_1)$ is 1, otherwise it is 0; when $\gamma_1 \le lnER_{i,t} \le \gamma_2$, $I(\gamma_1 \le lnER_{i,t} \le \gamma_2)$ is 1, otherwise it is 0; When $lnER_{i,t} \ge \gamma_2$, $I(lnER_{i,t} \ge \gamma_2)$ is 1, otherwise it is 0. From the threshold test results in Table 1, the environmental regulations can be divided into three intervals, interval one: $lnER_{i,t} \le -0.2665$, interval two: $-0.2665 \le lnER_{i,t} \le 3.6020$, interval three: $lnER_{i,t} \ge 3.6020$. Then this research focuses on analyzing the impact of environmental regulations on China's green economic performance in different intervals.

3.1.2. Dynamic Panel Single Threshold Model

The second part of the previous article theoretically analyzes the nonlinear effects of environmental regulations on digitalization, technological innovation, and industrial structure upgrade. This article builds a dynamic panel threshold model of environmental regulations on intermediary variables to verify its threshold effect. Before constructing the model, we conducted a threshold test and found that environmental regulation has a single-threshold effect on the intermediary variables, and it is significant at a significance level of 1%. Based on this, this research constructs a dynamic panel single-threshold model of environmental regulation for digitalization, as follows:

$$\begin{aligned} lnD_{i,t} = \mu_i + \beta_i lnX_{i,t} + \lambda_7 lnD_{i,t-1}\cdot I(lnER_{i,t} \le \gamma_1) + \lambda_8 lnD_{i,t-1}\cdot I(nER_{i,t} \ge \gamma_1) \\ + \alpha_4 lnER_{i,t}\cdot I(lnER_{i,t} \le \gamma_1) + \alpha_5 lnER_{i,t}\cdot I(lnER_{i,t} \ge \gamma_1) + \varepsilon_{i,t} \end{aligned} \quad (2)$$

Replacing lnD in the above model (2) with $lnTech$ and $lnIs$ is a dynamic panel single-threshold model of environmental regulation for technological innovation and industrial structure upgrade. Due to the length of the literature, this article does not list them.

3.1.3. Mediation Effect Model

Based on the analysis of the mechanism of environmental regulation on China's green economic performance in the second part, the impact of environmental regulation on green economic performance may not be direct, but through three transmission mechanisms: digital development, technological innovation, and industrial structure upgrade. This article refers to the intermediary effect test procedure of Wen et al. [24] to test the intermediary conduction effect of digital development, technological innovation, and industrial structure upgrade. This study constructs a mediating effect model, introduces digital development, technological innovation, and industrial technology upgrading, and analyzes its mediating effect in environmental regulation and dependent variable green economic performance.

Taking into account the green economic performance and the lag period of the intermediary variables, this paper incorporates the lag period of the dependent variable into the model to regress, and constructs a dynamic panel model of the intermediary effect with digitalization as the intermediary variable as follows:

$$lnGEP_{i,t} = \mu_i + \lambda_4 lnGEP_{i,t-1} + c_1 lnER_{i,t} + \beta_i lnX_{i,t} + \varepsilon_{i,t} \quad (3)$$

$$lnD_{i,t} = \mu_i + \lambda_5 lnD_{i,t-1} + c_2 lnER_{i,t} + \beta_i lnX_{i,t} + \varepsilon_{i,t} \quad (4)$$

$$lnGEP_{i,t} = \mu_i + \lambda_6 lnGEP_{i,t-1} + c_3 lnER_{i,t} + b_2 lnD_{i,t} + \beta_i lnX_{i,t} + \varepsilon_{i,t} \quad (5)$$

The above model (3) is a total effect model, model (4) is a mediating effect model with digital development as a mediating variable, and model (5) is a direct effect model. Replacing lnD in the above models (4) and (5) with $lnTech$ and $lnIs$ is the mediating effect model and the direct effect model with technological innovation and industrial structure upgrading as mediating variables, respectively. Due to the length of the article, it is not listed in this article. According to the related research of Fan et al., the system GMM estimation can solve the dynamic panel regression very well, and can effectively solve the endogenous problem brought by the lag term of the explained variable as the explanatory variable. Therefore, this paper chooses the system GMM estimation method to regress the above model.

3.2. Variable Selection and Measurement

3.2.1. Dependent Variable

(1) Measurement of China's green economy performance

Based on the research of Lin et al. [25] and Li et al. [26], this study considers the carbon emissions generated by energy consumption, adds carbon dioxide emissions to the undesired output, and uses the non-radial distance function of "multiple input, multiple outputs" to measure green economic performance. Under the established input elements, it realizes the maximum expected output and minimizes the undesired output. This paper divides the panel sample data into 1, 2, 3 ... N decision-making units, denoted by i, i ∈(1, 2, 3 ... 228); the time series is divided into 1, 2, 3 ... T periods, denoted by t, t∈(1, 2, 3 ... 16). The input elements of each region include labor (L), capital (K), and energy (E), the expected output is real GDP (Y), and the undesired output includes sulfur dioxide emissions (S), industrial wastewater emissions (W), industrial smoke and dust emissions (D), and carbon dioxide emissions (C). Therefore, the production function P constructed in this paper is expressed as in Formula (6):

$$P = \{L, K, E, Y; S, W, D, C\} \quad (6)$$

$$s.t \begin{cases} \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}L_{it} = L, \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}K_{it} = K, \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}E_{it} = E \\ \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}Y_{it} \geq Y, \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}S_{it} \leq S, \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}W_{it} \leq W \\ \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}D_{it} \leq D, \sum_{i=1}^{N}\sum_{t=1}^{T}\lambda_{it}C_{it} \leq C \\ \lambda_{it} \geq 0, i = 1, 2, \ldots, 228, t = 1, 2, \ldots, 17 \end{cases} \quad (7)$$

Formula (3) satisfies the following three conditions: (1) The expected output and the undesired output meet weak disposability, which means that the undesired output has a cost. (2) The zero intersection of expected output and undesired output means that undesired output is inevitable. (3) The ratio of increase or decrease between expected output and undesired output is inconsistent.

According to different research needs, before constructing the non-radial distance function, this research assigns weights to input–output variables and determines the direction vector. This study assumes that input factors, expected output, and expected output are equally important. Therefore, firstly, this article assigns 1/3 of the weight to the input factors, which include labor, capital, and energy. Therefore, the weights of the input factors are assigned to the three input factors on average, that is, the weights of L, K, and E are respectively 1/9. Secondly, the expected output is weighted by 1/3, the expected output is only determined as the actual GDP, so the weight of the actual GDP is 1/3. Thirdly, the weight of undesired output is 1/3, including four pollutant emissions, and the average weight of each pollutant emission is 1/12. Therefore, the weight vector determined in this research is as shown in Formula (8):

$$w = (w_L, w_K, w_E, w_Y, w_S, w_W, w_D, w_C) = \left(\frac{1}{9}, \frac{1}{9}, \frac{1}{9}, \frac{1}{3}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}, \frac{1}{12}\right) \tag{8}$$

According to the constraint conditions of the production function, corresponding to the weight vector, the direction vector determined in this study is as shown in Formula (9):

$$g = (-L, -K, -E, Y, -S, -W, -D, -C) \tag{9}$$

From the characteristics of the non-radial distance function, it can be seen that under the given input factors, the increase or decrease ratio of expected output and undesired output is inconsistent. The slack vector is determined as shown in Formula (10):

$$\beta = (\beta_L, \beta_K, \beta_E, \beta_Y, \beta_S, \beta_W, \beta_D, \beta_C) \tag{10}$$

Therefore, the non-radial distance function in this research can be expressed as shown in Formula (11):

$$\begin{gathered} NDDF(L, K, E, Y, S, W, D, C) \\ = max\left(\tfrac{1}{9}\beta_L + \tfrac{1}{9}\beta_K + \tfrac{1}{9}\beta_E + \tfrac{1}{3}\beta_Y + \tfrac{1}{12}\beta_S + \tfrac{1}{12}\beta_W + \tfrac{1}{12}\beta_D + \tfrac{1}{12}\beta_C\right) \cdot I(lnER_{i,t} \geq \gamma_2) + \alpha_1 lnER_{i,t} \end{gathered} \tag{11}$$

$$s.t \begin{cases} \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}L_{it} = L - \beta_L g_L, \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}K_{it} = K - \beta_K g_K, \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}E_{it} = E - \beta_E g_E \\ \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}Y_{it} \geq Y + \beta_Y g_Y, \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}S_{it} \leq S - \beta_S g_S, \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}W_{it} \leq W - \beta_W g_W \\ \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}D_{it} \leq D - \beta_D g_D, \sum_{i=1}^{N}\sum_{t=1}^{T} \lambda_{it}C_{it} \leq C - \beta_C g_C \\ \lambda_{it} \geq 0, i = 1, 2, \ldots, 228, t = 1, 2, \ldots, 17, \beta \geq 0 \end{cases} \tag{12}$$

Solving Formulas (11) and (12), we can find the optimal slack variable solution for input and output:

$$\beta^* = (\beta^*{}_{L,it}, \beta^*{}_{K,it}, \beta^*{}_{E,it}, \beta^*{}_{Y,it}, \beta^*{}_{S,it}, \beta^*{}_{W,it}, \beta^*{}_{D,it}, \beta^*{}_{C,it}) \tag{13}$$

According to the optimal slack ratio of each input and output, the target value of each input and output is calculated: (1) Target value of input elements: target value of labor $(L) = L_{it} - \beta^*{}_{L,it} \times L_{it}$, target value of capital $(K) = K_{it} - \beta^*{}_{K,it} \times K_{it}$, target value of energy $(E) = E_{it} - \beta^*{}_{E,it} \times E_{it}$; (2) Target value of expected output: target value of actual GDP $(Y) = Y_{it} + \beta^*{}_{Y,it} \times Y_{it}$; (3) Target value of undesired output: target value of sulfur dioxide $(S) = S_{it} - \beta^*{}_{S,it} \times S_{it}$, target value of industrial wastewater discharge $(W) = W_{it} - \beta^*{}_{W,it} \times W_{it}$, target value of industrial soot emission $(D) = D_{it} - \beta^*{}_{D,it} \times D_{it}$, target value of carbon dioxide $(C) = C_{it} - \beta^*{}_{C,it} \times C_{it}$. When $\beta^*{}_{it} = 0$, it indicates that this decision-making unit has reached the optimum in this input or output.

Based on the optimal target value of each input and output, this research uses the actual value of target energy intensity to represent the energy emission performance (*EP*) indicator, where energy intensity is expressed as the ratio of energy input to t expected output. In addition, this study uses the target pollutant emission intensity as a proportion of the actual emission intensity to construct the pollution emission performance (*PEP*) indicator, where the pollutant emission intensity is expressed by the weighted average of the ratio of the four pollutant emissions to the expected output. Finally, this study uses the weighted average of energy emission performance and pollution emission performance to express the green economic performance (*GEP*) to integrate the impact of energy and pollution emissions. The specific calculation formula is as follows:

$$EP = \frac{(E_{it} - \beta^*{}_{E,it} \times E_{it})/(Y_{it} + \beta^*{}_{Y,it} \times Y_{it})}{E_{it}/Y_{it}} \tag{14}$$

$$\begin{aligned} PEP = {} & \frac{1}{4}\frac{(S_{it}-\beta^*{}_{S,it}\times S_{it})/(Y_{it}+\beta^*{}_{Y,it}\times Y_{it})}{S_{it}/Y_{it}} + \frac{1}{4}\frac{(W_{it}-\beta^*{}_{W,it}\times W_{it})/(Y_{it}+\beta^*{}_{Y,it}\times Y_{it})}{W_{it}/Y_{it}} \\ & + \frac{1}{4}\frac{(D_{it}-\beta^*{}_{D,it}\times D_{it})/(Y_{it}+\beta^*{}_{Y,it}\times Y_{it})}{D_{it}/Y_{it}} + \frac{1}{4}\frac{(C_{it}-\beta^*{}_{C,it}\times C_{it})/(Y_{it}+\beta^*{}_{Y,it}\times Y_{it})}{C_{it}/Y_{it}} \end{aligned} \tag{15}$$

$$GEP = \frac{1}{2}EP + \frac{1}{2}PEP \tag{16}$$

(2) Input–output variables and data description

This research adopts the non-radial distance function of "multiple input and multiple outputs" to measure China's green economy performance indicators, and the calculation formula is shown in Section 3.2.1. The specific measurement methods of each input–output element are shown in Table 2.

Table 2. Input–output variables and data descriptions for measuring green economic performance.

Variable		Variable Measurement
Inputs	*L*	Several employees in units at the end of the year in prefecture-level cities in China.
	K	Using 2000 as the base period, use the perpetual inventory method to calculate the capital stock of China's prefecture-level cities from 2003 to 2019.
	E	Total energy consumption in various regions of China (including coal, coke oil, crude oil, gasoline, kerosene, diesel, fuel oil, liquefied petroleum gas, natural gas, and electricity).
Expected outputs	*Y*	Using 2000 as the base period, calculate the actual GDP of China from 2003 to 2020.
Undesired outputs	*S*	Sulfur dioxide emissions from prefecture-level cities in China.
	W	Discharge of industrial wastewater in prefecture-level cities in China.
	D	Industrial smoke and dust emissions of prefecture-level cities in China.
	C	Refer to the method given by the Intergovernmental Panel on Climate Change (2006) to calculate the carbon dioxide emissions of prefecture-level cities through energy consumption, average heat generation, and carbon emission coefficients.

(3) Green economy performance measurement results

This paper calculates the energy performance and environmental performance of 228 prefecture-level cities in China from 2003 to 2019, and comprehensively obtains the green economic performance. Figure 2 depicts the comparison of energy performance and environmental performance in 2019. The slash is a 45-degree line. The energy performance of prefecture-level cities above the slash is better than the environmental performance, while the opposite is true below the slash. According to the result indicators in Figure 2, 80% of the cities are located on the diagonal, indicating that in 2019, most cities maintained stable development of energy performance and environmental performance. However, among the 228 cities, 35 cities have higher energy performance than environmental performance, while 11 cities have lower energy performance. This shows that during the implementation of China's energy-saving and emission-reduction policies in recent years, energy-saving achieved better results than emission reduction. The green economic performance is between 0 and 1. The higher the value, the better the green economic performance. Among them, 121 cities are located between 0.8 and 1, such as Beijing, Shanghai, Shenzhen and other high-level development areas. There are 75 cities located between 0.6–0.8, such as Jining, Yichang, Zhuhai and other middle-level development areas. There are 32 cities located between 0.4 and 0.6, such as Guiyang, Pingliang and other low-level development areas. It can be seen that China's green economy performance is generally at a relatively high level, which shows that against the background of carbon neutrality, the energy environment has made remarkable achievements.

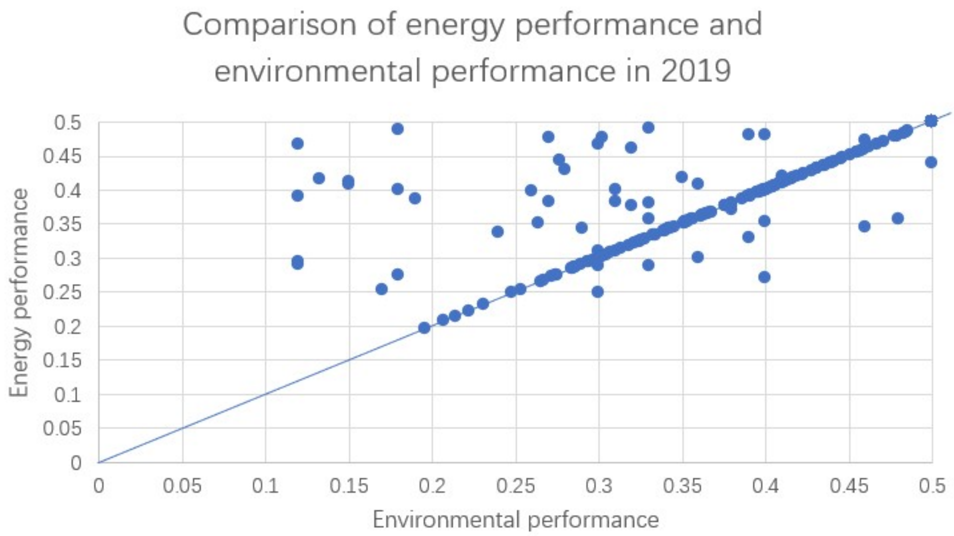

Figure 2. Comparison of energy performance and environmental performance in 2019.

3.2.2. Independent Variable

Environmental Regulation (*ER*). Since direct measurement indicators of environmental regulations are difficult to obtain, scholars use different alternative indicators for measurements, such as investment in environmental pollution control, the amount of pollutant discharge fees per unit, the number of environmental regulations issued by local governments, and so on. Taking into account the availability of data from prefecture-level cities in China, this study draws on the comprehensive measurement method of Dong et al. [27] for measurement. First, calculate the unit economic pollution emissions of the "three wastes" of each city $x_{ij} = u_{i,j}/y_{i,j}$, $u_{i,j}$ represents the *i*-th city's type j pollution emissions, $y_{i,j}$ represents the regional economic output; then standardize it $x'_{i,j} = (maxx_{i.j} - x_{i.j})/(maxx_{i.j} - minx_{i.j})$. Second, determine the weight of each pollutant emission $w_{i,j} = x_{i.j}/x_{i.j}$. Finally, comprehensively measure the intensity of environmental regulations $ER = \sum_{j=1}^{3} x'_{i,j} \times w_{i,j}$. In the robustness test, this research uses the ratio of energy consumption to regional GDP to measure environmental regulations. Since this alternative indicator is a reverse indicator, the reciprocal of this indicator is taken to positively change the reverse indicator.

3.2.3. Mediating Variables

(1) Technological innovation (*Tech*). This article uses the proportion of scientific research funding and economic output in each region to measure technological innovation. In the robustness test, it is measured by the proportion of personnel engaged in scientific research and technical services and employees in the unit. (2) Industrial structure upgrade (*Is*). This paper uses the ratio of the output value of the tertiary industry to the output value of the secondary industry to measure the industrial structure upgrade. In the robustness test, it is measured by the ratio of the output value of the tertiary industry to the regional GDP. (3) Digitalization (*D*). This article comprehensively measures regional digitalization from three secondary indicators of prefecture-level city digitalization foundation, digitalization application, and digitalization development. Digitalization foundation includes 5 three-

level indicators: optical cable length per 10,000 square kilometers, per capita long-distance telephone exchange capacity, per capita local telephone exchange capacity, per capita mobile phone exchange capacity, and per capita Internet broadband access ports; digital application includes three three-level indicators: mobile phone penetration rate, Internet penetration rate, and per capita fixed phone users; digital development includes three three-level indicators: the proportion of digital industry personnel, the proportion of digital industry revenue, and the proportion of digital industry fixed assets. This study uses the entropy TOPSIS method to weight these 11 three-level indicators to obtain a comprehensive score.

3.2.4. Control Variables

This article draws on the research of Li et al. [28], Dong et al. [27], and Fan Dan et al. [15], and selects administrative control, urbanization, degree of openness, fiscal decentralization, and human capital as the control variables of this article. (1) Government administrative control (*Gov*): the ratio of government fiscal expenditure to regional GDP; (2) Urbanization (*Urb*): the ratio of urban population to the total population; (3) Openness (*Open*): the ratio of regional import and export volume to regional GDP; (4) Human capital (*Z*): this article adopts the average years of education method proposed by Barro and Lee, and multiplies the number of years of education by the ratio of the area's population with an education level to the total population. That is $Z = \sum Q_{i,t,j} \times U_j$, $Q_{i,t,j}$ is the ratio of the education level population to the total population of the j level in the t year in the i district, and U_j represents the number of years of education at level j. This article divides the j level into 1, 2, and 3 levels (primary school, middle school, general higher school), U_j = 6, 12, 16.

3.3. Data Sources and Description

This research collects data of prefecture-level cities in China from 1997 to 2019 to measure relevant variables. However, due to the lack of indicator data for individual prefecture-level cities, the data of 228 prefecture-level cities from 2003 to 2019 are finally selected as the data sample. The original data comes from "China Statistical Yearbook", "China City Statistical Yearbook", "China Energy Statistics", "China Environment Statistical Yearbook", "China Science and Technology Statistical Yearbook" and "China Electronic Information Industry Statistical Yearbook".

4. Results and Discussion

4.1. Variable Descriptive Statistics

A descriptive statistical analysis of the variables from 2003 to 2019 of 228 prefecture-level cities in China is presented in Table 3. It shows that the average value of Green Economic Performance (*GEP*) is 0.806, the minimum value is 0.065, the maximum value is 1, and the standard deviation is 0.194, indicating that the green economic performance of different cities in China is quite different. These findings are similar to those of Li et al. [26] and Guo et al. [29]. The intensity of environmental regulations (*ER*) presents the characteristics of "small mean value and large standard deviation", indicating that the intensity of environmental regulations varies between different regions. From the perspective of intermediary variables, the standard deviations of digitalization (*D*), green technological innovation (*Tech*), and industrial structure upgrade (*Is*) are all relatively large, indicating that there are obvious differences in the level of direct digital development, technological innovation, and industrial structure upgrades in different cities. From the perspective of control variables, there are obvious differences in the degree of administrative control (*Gov*), urbanization level (*Urb*), openness (*Open*), and human capital education (*Z*) of different prefecture-level cities.

Table 3. Descriptive statistics.

Variable	Observations	Mean	Std.Dev	Minimum	Maximum
GEP	3876	0.806	0.194	0.065	1
ER	3876	0.276	0.523	0.001	4.927
D	3876	2.658	0.144	1.665	2.843
Tech	3876	0.015	0.020	0.001	0.37
Is	3876	0.884	0.457	0.009	9.482
Gov	3876	0.186	0.287	0.01	8.701
Urb	3876	0.132	0.161	0.027	6.597
Open	3876	0.112	0.165	0.001	2.766
Z	3876	1.214	0.468	0.211	4.866

Note: Std.Dev. denotes the standard deviation.

4.2. Empirical Results of Dynamic Panel Dual-Threshold Model

According to the results in Table 4a,b, the relationship between environmental regulation and green economic performance presents a "U"-shaped relationship that first decreases and then increases, and has a nonlinear relationship with two thresholds. Table 4a reports the empirical results of the dual threshold of environmental regulations affecting China's green economic performance, and Table 4b reports the threshold value of environmental regulations in each city.

It can be seen from Table 4a that the double thresholds of environmental regulations are -0.267 and 3.602, respectively, and environmental regulations can be divided into three intervals. The first interval is when $lnER < -0.267$, the impact of environmental regulations on green economic performance is significantly negative at a significance level of 1%. The reason for this result may be that the application of the digital governance system is not so urgent. There is no compulsory restriction on the environmental requirements of enterprises and society, and enterprises have relatively loose restrictions on environmental regulations, reducing the resources of enterprises for technological innovation. Moreover, weak environmental regulations are not conducive to the upgrading of the industrial structure. High-pollution and high-consumption industries continue to increase production, increasing undesired output, resulting in a reduction in green economic performance. It can be seen from Table 4b that cities in central and western China, such as Shanxi, Liaoning, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hunan, Sichuan, and Shaanxi Province, were in the first range from 2003 to 2005. This shows that the intensity of environmental regulations in the central and western regions of China is not very strong, and the awareness of environmental protection is weak. A possible reason for this is that China did not include the environmental protection target responsibility system in the "Eleventh Five-Year Plan" before 2005, and the economic development level of China's central and western regions is not high, technological innovation capabilities need to be strengthened, and the strength of environmental regulations is weak, which is not conducive to green economic performance. However, from 2006 to 2019, no city was in the first range, which shows that the requirements of the "Decision" and "Outline" in China's "Eleventh Five-Year Plan" in 2006 were implemented. The Chinese government has increased the intensity of environmental regulations, and the level of economic development, digital application, and technological innovation in various regions has been further improved.

Table 4. (**a**) The empirical results of the dynamic panel dual threshold of the impact of environmental regulations on China's green economic performance. (**b**) The threshold value of environmental regulations in various cities in China.

(a)

Variables	Threshold Interval of Environmental Regulation		
	$lnER < -0.267$	**$-0.267 < lnER < 3.602$**	**$lnER > 3.602$**
$lnGEP_{i,t-1}$	0.436 *** (9.46)	0.227 *** (10.39)	0.083 *** (4.60)
$lnER$	−0.061 *** (−4.39)	0.043 *** (0.043)	0.036 *** (11.49)
$lnGov$	−0.254 *** (−33.76)	−0.254 *** (−33.76)	−0.254 *** (−33.76)
$lnUrb$	−0.128 *** (−7.87)	−0.128 *** (−7.87)	−0.128 *** (−7.87)
$lnOpen$	0.014 *** (2.98)	0.014 *** (2.98)	0.014 *** (2.98)
lnZ	0.122 *** (8.82)	0.122 *** (8.82)	0.122 *** (8.82)
C	−1.068 *** (−22.49)	−1.068 *** (−22.49)	−1.068 *** (−22.49)
R^2	0.3020	0.3020	0.3020
Observations	3648	3648	3648
F test	147.55	147.55	147.55

(b)

2003–2005	**Main Central and Western Cities in China:** Datong, Yangquan, Shuozhou, Zhezhou, Benxi, Chaoyang, Jilin, Tonghua, Hegang, Mudanjiang, Huainan, Ma'anshan, Huaibei, Jingdezhen, Ji'an, Anyang, Xinxiang, Jiaozuo, Xiangtan, Shaoyang, Yiyang, Huaihua, Loudi, Luzhou, Neijiang, Leshan, Meishan, Yibin, Baoji, Xianyang, Weinan, etc.	**Main Eastern Cities in China:** Cities in Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong Province, etc., as well as cities with better development in the central and western regions.	No
2006–2009	No	**Main Peripheral Cities in China:** Cities other than China's provincial capitals, municipalities directly under the Central Government, and negative provincial capitals.	**Main Central Cities in China:** Beijing, Tianjin, Taiyuan, Shenyang, Changchun, Harbin, Daqing, Shanghai, Wenzhou, Hefei, Fuzhou, Putian, Ningde, Jinan, Qingdao, Yantai, Weihai, Zhengzhou, Xuchang, Wuhan, Changsha, Guangzhou, Shenzhen, Yangjiang, Jieyang, Chengdu, Nanchong, Bazhong, Zunyi, Kunming, Yan'an, etc.

Note: *** indicates that the regression coefficient is significant at the level of 1%.

The second interval is when $-0.267 < lnER < 3.602$, the impact of environmental regulations on green economic performance is significantly positive at a significance level of 1%, with a coefficient of 0.043. In this interval, the intensity of environmental regulation is appropriate. Driven by the time effect, the application of a digital governance system and the application of digitalization in environmental supervision and pollution control have strengthened the enforcement of environmental regulations and promoted China's green economic performance. At the same time, the appropriate intensity of environmental regulations can force Chinese enterprises to carry out green technological innovation, and enterprises can improve technological innovation under the influence of external pressure and internal incentives. Moreover, appropriate environmental regulations raise the barriers to entry for high-polluting industries through their barrier effects. High-polluting industries have to increase investment in clean production equipment for companies, promote the development of clean energy industries, reduce high-pollution and high-energy-consumption industries, and promote green economic performance. From 2003 to 2005, cities in eastern China, such as Beijing, Tianjin, Hebei, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, and Guangdong, were in the second zone. This shows that cities in the eastern region have a relatively high level of economic development, strong environmental awareness, strong capability to implement various governments' environmental regulations, technological innovation capabilities, and appropriate environmental regulations, which can effectively promote green economic performance. From 2006 to 2019, all cities except provincial capitals, municipalities, and sub-provincial capitals were located in this range. This shows that with time, the widespread application of digitalization in various regions, technological innovation capabilities, and industrial structure upgrades were further improved, and environmental regulations were appropriate, which has the greatest effect on promoting green economic performance.

The third interval is when $lnER > 3.602$, the impact of environmental regulations on green technology innovation is significantly positive, at a significance level of 1%, with a coefficient of 0.036. In this interval, China's environmental regulations are relatively strong, and have strong constraints on enterprises and society. With the help of digital applications and technological innovations, the performance of the green economy has improved, but high-strength environmental regulations cannot internalize the costs caused by environmental regulations for companies with high pollution, high emissions, and high costs. Most of these companies chose to transfer to other places and chose regions with weaker environmental regulations to transfer to, so that the growth rate of undesired output has been reduced. Therefore, with the increased intensity of environmental regulations, the impact of environmental regulations on green economic performance has decreased, with the coefficient falling from 0.043 to 0.036, but it still promotes green economic performance. From 2003 to 2005, no city was located in this range, indicating that there were no cities with high-strength environmental regulations during this period. However, after 2006, China's central cities, such as provincial capitals, municipalities directly under the Central Government, and sub-provincial capitals, were located in this range. This shows that the intensity of environmental regulations in central cities is too high, which is not conducive to the effective promotion of green economic performance, and that the intensity of environmental regulations should be weakened appropriately.

The regression results of other control variables in Table 4a show that administrative control ($lnGov$) and urbanization level ($lnUrb$) are significantly negative at the 1% level. This shows that the stronger the administrative control, the greater the pollution emission pressure of enterprises, and the reduction of resources for green technology innovation is not conducive to the performance of the city's green economy; the higher the level of urbanization, the greater the effect of urban population agglomeration. A large inflow of population will increase urban energy consumption and undesired output emissions, and reduce urban green economic performance, which is consistent with the research results of Sun et al. [30]. The degree of openness ($lnOpen$) and human capital (lnZ) are positive at a significance level of 5%, indicating that the higher the degree of openness and the higher the human capital education, the more conducive to the improvement of green economic performance. The reason for this may be that the higher the degree of opening to the outside world, the more foreign investment can be attracted. The expansion of the scale of China's new energy companies, the more abundant cash flow, and the greater capital density are more conducive to green technology innovation, increased energy input, reduced undesired output, and the promotion of green economic performance in the company. The higher human capital, increased local environmental protection knowledge, and knowledge spillover can lead to increased local per capita environmental awareness, enhananced decrease in undesired output, and promotion of green economic performance. This is consistent with the research results of Sun et al. [31]. In summary, the results verify Hypothesis 1, that is, environmental regulations of different intensities have a nonlinear relationship with green economic performance.

4.3. Analysis of Regional Heterogeneity

According to variable descriptive statistical analysis, green economic performance and environmental regulation intensity have obvious heterogeneity in regional distribution. Therefore, this article conducts an in-depth discussion on the possible regional differences in the impact of environmental regulations on green economic performance. Concerning the research of Wang et al. [32] and Huang et al. [33], this paper divides the panel data of 228 prefecture-level cities into central cities and peripheral cities according to their degree of economic development, and divides them into cities in the eastern region and cities in the central and western regions according to their geographic location. Central cities include municipalities directly under the central government, sub-provincial cities, and provincial capital cities. The threshold effect test is performed first, and it is found that there is a single-threshold effect in each category area. The reason for the single-threshold effect between different cities may be the difference in economic development and environmental enforcement between regions, which also leads to the threshold effect of environmental regulation and green innovation performance. Then, the single-threshold model presented as model (1) is subjected to regression analysis. The regression results are shown in Table 5a,b.

The results in Table 5a show that the environmental regulation thresholds of central cities and peripheral cities are both around −0.2, and the regression coefficients are both significant at the 1% significance level. However, the coefficient of central cities is smaller than that of peripheral cities, and the impact of central city environmental regulation on green economic performance is less than that of peripheral cities. This result may be due to the fact that the economic development of central cities is higher than that of peripheral cities, the implementation time of environmental regulations in central cities is faster than that of peripheral cities, and the control of environmental pollution is stronger, as well as there being undesirable regional reductions. When the intensity of environmental regulation is weak, the effect of restraining green economic performance is less than that in peripheral cities; when the intensity of environmental regulation is strengthened, due to the mandatory and deterrent nature of the system, the reduction of pollution emissions in peripheral cities is greater than that in central cities. Therefore, in general, the elasticity of changes in environmental regulations in central cities due to time and policy effects is less than that in peripheral cities.

The results in Table 5b show that the threshold value in the eastern region is −0.968, and the threshold value in the central and western regions is −0.267. The regression coefficients of urban environmental regulations in the eastern and central and western regions are both significant at a significance level of 1%. The intensity of regional environmental regulations affecting green economic performance is higher than that of the central and western regions. This result may be due to the effective implementation of environmental regulations and policies in the eastern region, with its inherent economic, technological, and geographical advantages. In addition, the digital economy in the eastern region developed earlier, and technological innovation and industrial structure upgrades are also superior to those in the central and western regions, making the impact of environmental regulations on the performance of the green economy stronger.

Table 5. (**a**) Test results of regional heterogeneity of environmental regulations affecting green economic performance. (**b**) Test results of regional heterogeneity of environmental regulations affecting green economic performance.

(**a**)

Variable	Central City		Outer City	
	$lnER < -0.246$	$lnER > -0.246$	$lnER < -0.193$	$lnER > -0.193$
$lnGEP_{i,t-1}$	0.018 (0.15)	0.404 *** (9.54)	0.395 *** (8.73)	0.129 *** (8.35)
$lnER$	−0.114 *** (−2.85)	0.021 *** (3.88)	−0.053 *** (−3.70)	0.046 *** (15.07)
$X_{i,t}$	YES	YES	YES	YES
C	−0.453 (−4.29)	−0.453 (−4.29)	−1.109 *** (−21.85)	−1.109 *** (−21.85)
R^2	0.2803	0.2803	0.3136	0.3136
Observations	432	432	3216	3216
F test	19.33	19.33	171.70	171.70

(**b**)

Variable	Cities in Eastern China		Cities in Central and Western China	
	$lnER < -0.968$	$lnER > -0.968$	$lnER < -0.267$	$lnER > -0.267$
$lnGEP_{i,t-1}$	−0.738 *** (−3.58)	0.120 *** (4.60)	0.427 *** (8.33)	0.142 *** (8.09)
$lnER$	−0.064 ** (−2.37)	0.052 *** (11.50)	−0.058 *** (−3.51)	0.042 *** (12.35)
$X_{i,t}$	YES	YES	YES	YES
C	−1.114 *** (−16.98)	−1.114 *** (−16.98)	−1.112 *** (−17.67)	−1.112 *** (−17.67)
R^2	0.2754	0.2754	0.3104	0.3104
Observations	1168	1168	2480	2480
F test	51.65	51.65	130.35	130.35

Note: **, *** indicate that the regression coefficient is significant at the level of 5%, and 1%.

4.4. Robustness Test

4.4.1. Changing the Variable Measurement Method

In this study, the measurement method of environmental regulation was replaced by the ratio of energy consumption to regional GDP, and then model (1), above, was used to retest. The regression results are shown in Table 6. The results show that the impact of environmental regulations on green economic performance has a double-threshold effect, and the threshold values are −0.192 and 4.115, respectively. This result does not change the main research conclusions of this article.

Table 6. Robustness test results of the nonlinear impact of environmental regulations on green economic performance.

	Changing the Variable Measurement Method	Independent Variable Lags by One Period	Independent Variable Lags by Two Periods	2003–2006	2007–2019
First threshold	−0.192	−0.057	−0.540	2.763	−1.056
Second threshold	4.115	3.231	1.737	−1.843	3.632
$X_{i,t}$	YES	YES	YES	YES	YES
R^2	0.4085	0.2486	0.2847	0.5658	0.3236
Observations	3648	3648	3420	456	3192
F test	235.52	112.84	126.64	28.40	141.29

4.4.2. The Independent Variable Lags by One Period and Two Periods Behind

The one and two lagging independent variables of environmental regulation are included in model (1) for regression. Table 6, presenting the regression results, shows that the impact of environmental regulation on green economic performance has a double-threshold effect, and different intensities of environmental regulation manifest green economic performance. The nonlinear relationship is consistent with the previous results.

4.4.3. Regression by Period

In the 2006 11th Five-Year Plan, to implement the requirements of the "Decision" and "Outline", the environmental protection target responsibility system was included in the government's performance evaluation [34]. The Chinese government increased the intensity of environmental regulations. Since then, 2006 has been regarded as a watershed for changes in the intensity of environmental regulations. Therefore, this study selects 2006 as the node and regresses the two time periods 2003–2006 and 2007–2019. The regression results in Table 6 show that there is a nonlinear relationship between environmental regulations and green economic performance in different periods. The difference is that from 2003 to 2006, environmental regulations showed a threshold effect of first raising and then suppressing green economic performance, while 2007–2019 showed a threshold effect of first suppressing and then raising. This result did not change the main research conclusion of this article.

4.5. Further Research

4.5.1. The Dynamic Single-Threshold Effect of Environmental Regulations on Intermediary Variables

Table 7 shows the results of the threshold regression of environmental regulations on the three intermediary variables. The results show that:

(1) Environmental regulations have a single-threshold effect on digitalization, with a threshold value of 2.955, which is within the range of appropriate intensity of environmental regulations. When $lnER < 2.955$, the coefficient of environmental regulation $lnER$ is 0.029, when $lnER > 2.955$, the coefficient of environmental regulation $lnER$ is 0.040, and both are significantly positive at the 1% significance level. This shows that environmental regulation has a nonlinear relationship with digitalization, but it has a positive effect on the whole. That is, as the intensity of environmental regulation increases, the government increases the application of digital environmental governance systems, and the role of digitalization becomes stronger and stronger.

(2) The threshold value of environmental regulation for technological innovation is 3.957, which is in the range of high-strength environmental regulation. When $lnER < 3.957$, the strength of environmental regulations is appropriate, and the coefficient of environmental regulations $lnER$ is 0.034. When $lnER > 3.957$, the strength of environmental regulations is stronger, and the coefficient of environmental regulations $lnER$ is 0.151, and both are significantly positive at the 1% significance level. This shows that the effect of environmental regulation on technological innovation is nonlinear, but it has a positive impact on the whole, and the stronger the intensity of environmental regulation, the greater the pressure on technological innovation of enterprises, and the more conducive to strengthening technological innovation of enterprises.

(3) The threshold value of environmental regulation for the upgrading of industrial structure is 2.249, which is in the range of environmental regulation with appropriate intensity. When $lnER < 2.249$ and the intensity of environmental regulation is weak, the coefficient of environmental regulation $lnER$ is -0.033. It shows that when environmental regulations are weak, China's development stage is dominated by secondary industry; in particular, heavy industries with high pollution and energy consumption continue to produce and discharge pollution. Environmental regulations have not yet exerted a threshold effect, which is not conducive to the upgrading of industrial structures. When $lnER > 2.249$, the coefficient of environmental regula-

tion $lnER$ is 0.020, which indicates that the intensity of environmental regulation is strengthened, the entry threshold of high-polluting industries has increased, and the "barrier effect" is brought about, and at the same time, the upgrading of industrial structure is promoted through resource allocation and survival of the fittest. Based on the above analysis, this study can verify hypotheses 2a, 3a, and 4a, that is, environmental regulations of different intensities have a nonlinear relationship with digital development, technological innovation, and industrial structure upgrade.

Table 7. Regression results of the threshold of environmental regulation on intermediary variables.

Variable	*lnD*		*lnTech*		*lnIs*	
	$lnER < 2.955$	$lnER > 2.955$	$lnER < 3.957$	$lnER > 3.957$	$lnER < 2.249$	$lnER > 2.249$
$lnD_{i,t-1}$	0.523 *** (43.55)	0.415 *** (29.61)				
$lnTech_{i,t-1}$			0.284 *** (17.27)	0.412 *** (18.38)		
$lnIs_{i,t-1}$					0.318 *** (10.45)	0.735 *** (47.03)
$lnER$	0.029 *** (6.84)	0.040 *** (14.53)	0.034 * (1.88)	0.151 *** (7.44)	−0.033 *** (−4.08)	0.020 *** (8.29)
$X_{i,t}$	YES	YES	YES	YES	YES	YES
C	0.848 *** (21.60)	0.848 *** (21.60)	−2.605 *** (−14.49)	−2.605 *** (−14.49)	0.094 *** (2.28)	0.094 *** (2.28)
R^2	0.6977	0.6977	0.2824	0.2824	0.5582	0.5582
Observations	3648	3648	3648	3648	3648	3648
F test	787.12	787.12	134.19	134.19	430.88	430.88

Note: *, *** indicate that the regression coefficient is significant at the level of 10%, and 1%.

4.5.2. Analysis of Mediation Effect

Table 8a–c show, respectively, the GMM regression results of the dynamic panel system with digital development, technological innovation, and industrial structure upgrade as the mediating variables. From the regression results in Table 8a, it can be seen that the P values of $AR(1)$ and $AR(2)$ of models (3)–(5) show that the null hypothesis that "the disturbance term has no autocorrelation" cannot be rejected. Hansen's test results show that the null hypothesis that "all instrumental variables are exogenous" cannot be rejected. This shows that the system GMM and tool variables in this paper are reasonable.

Among the test results of the three models in Table 8a–c, model (3) is the same model, which represents the total effect model of environmental regulations on green economic performance. Model (3) in Table 8a is the regression result of the total effect. The results show that environmental regulations have significantly promoted green economic performance, and the lagging green economic performance has a positive and significant impact on itself. It shows that after controlling for administrative control, urbanization, opening to the outside world, and human capital variables, the environmental regulations generally promoted the growth of green economic performance. Model (4) is the regression result of the mediating effect with digital development as a mediating variable, and it examines the impact of environmental regulations on digitalization. The results show that the effect of environmental regulations on digitalization is significantly negative, and digitalization has a positive impact on itself. Model (5) is the result of direct effect regression. The results show that environmental regulation has a significant positive impact on green economic performance, but digitalization has a significant negative impact on green economic performance, and the lagging period of green economic performance also has a significant positive impact on itself.

Table 8. (**a**) System GMM regression results—digital development as a mediating variable. (**b**) System GMM regression results—technological innovation as a mediating variable. (**c**) System GMM regression results—industrial structure upgrade as a mediating variable.

(**a**)

Variable	Model (3)	Model (4)	Model (5)
	lnGEP	***lnD***	***lnGEP***
$lnGEP_{i,t-1}$	0.196 *** (8.12)		0.175 *** (8.84)
$lnD_{i,t-1}$		0.484 *** (8.37)	
$lnER$	0.043 *** (7.02)	0.02 * (4.90)	0.036 *** (6.59)
lnD			0.210 *** (5.39)
$X_{i,t}$	YES	YES	YES
C	−0.839 *** (−5.79)	1.678 *** (9.40)	−1.456 *** (−8.77)
$AR(1)$	0.300	0.556	0.253
$AR(2)$	0.503	0.260	0.460
Hansen	0.556	0.674	0.517

(**b**)

Variable	Model (3)	Model (4)	Model (5)
	lnGEP	***lnTech***	***lnGEP***
$lnGEP_{i,t-1}$	0.196 *** (8.12)		0.231 *** (10.53)
$lnTech_{i,t-1}$		0.37 *** (11.91)	
$lnER$	0.043 *** (8.89)	0.19 ** (1.29)	0.033 *** (7.02)
$lnTech$			0.065 *** (−5.78)
$X_{i,t}$	YES	YES	YES
C	−0.839 *** (−5.79)	−0.695 * (−1.97)	−1.202 *** (−8.57)
$AR(1)$	0.300	0.139	0.200
$AR(2)$	0.503	0.221	0.138
Hansen	0.556	0.693	0.701

(**c**)

Variable	Model (3)	Model (4)	Model (5)
	lnGEP	***lnIs***	***lnGEP***
$lnGEP_{i,t-1}$	0.196 *** (8.12)		0.191 *** (7.54)
$lnIs_{i,t-1}$		0.713 *** (6.92)	
$lnER$	0.043 *** (7.02)	0.14 *** (3.02)	0.042 *** (7.15)
$lnIs$			0.020 * (−0.61)
$X_{i,t}$	YES	YES	YES
C	−0.839 *** (−5.79)	0.465 *** (3.73)	−0.7766 *** (−5.85)
$AR(1)$	0.300	0.210	0.243
$AR(2)$	0.503	0.079	0.329
Hansen	0.556	0.809	0.356

Note: *, **, *** indicate that the regression coefficient is significant at the level of 10%, 5%, and 1%.

Model (4) in Table 8b is the regression result of indirect effects, which examines the impact of environmental regulations on technological innovation. The results show that environmental regulation has a significant positive effect on digitalization, and technological innovation that lags has a positive impact on itself. Model (5) is the result of direct effect regression. The result shows that environmental regulations and technological innovation have a significant positive impact on green economic performance, and the lagging period of green economic performance also has a significant positive impact on itself.

Model (4) in Table 8c is the regression result of indirect effects, which examines the impact of environmental regulations on the upgrading of industrial structures. The results show that environmental regulation has a significant positive effect on the upgrading of industrial structures, and the lagging industrial structure upgrade has a positive impact on itself. Model (5) is the result of direct effect regression, and the result shows that environmental regulations, industrial structure upgrades, and a lagging period of green economic performance all have a significant positive impact on green economic performance.

According to the above empirical results, the mediation effect can be analyzed: the coefficients of the independent variables to the dependent variables in the three models in Table 8a–c are all significantly positive at the 5% significance level. According to Wen's mediating effect test research, it can be concluded that there is a mediating effect between environmental regulation and green economic performance, and there is a partial mediating effect. According to the calculation formula of the relevant literature, it can be calculated that the digital mediation effect accounts for 9.767% of the total effect $((0.02 \times 0.210)/0.043)$; the intermediary effect of technological innovation accounts for 28.72% of the total effect $((0.19 \times 0.065)/0.043)$; the mediation effect of industrial structure upgrade accounted for 6.51% of the total effect $((0.14 \times 0.02)/0.043)$. This conclusion validates hypotheses 2b, 3b, and 4b, that is, environmental regulation acts in the performance of the green economy through digital development, technological innovation, and industrial structure upgrade.

5. Conclusions and Policy Implications

Based on the background of China's "carbon neutral" policy and the booming digitalization, combined with the specific measures of current environmental regulation policies, this study uses the dynamic panel threshold model and the systematic GMM method to study the impact of environmental regulations on green economic performance in prefecture-level cities in China and then interprets how China's environmental regulations can achieve the coordinated development of environmental protection and economic growth. According to the empirical outcomes, we draw the following conclusions: first, the performance of China's green economy is reduced following the addition of carbon dioxide emissions from energy consumption. In addition, environmental regulations have a dual-threshold nonlinear impact on China's green economic performance, and the nonlinear threshold values are different in different regions. Second, the overall change elasticity of the threshold effect of central cities is less than that of peripheral cities, and the intensity of environmental regulation in the eastern region that affects green economic performance is higher than that of the central and western regions. Third, further research found that in the context of the digital age, the degree of impact of environmental regulations on green economic performance is affected by digitalization. In addition, the first threshold effect of environmental regulations on green economic performance is mainly caused by the threshold effect of environmental regulations on digitalization. Fourth, the resource effect and reversal effect of environmental regulation have a two-way effect on technological innovation, and the barrier effect and resource effect of environmental regulation also have a two-way effect on upgrading industrial structure. In addition, the second threshold effect of environmental regulations on green economic performance is mainly caused by the threshold effect of environmental regulations on technological innovation and industrial structure upgrade. The empirical analysis of this study recommends the following policy implications:

(1) Reasonably match environmental regulatory policies with the level of regional economic development. The Chinese government should comprehensively use various environmental regulatory tools, such as environmental protection subsidies and pollution emission rights trading, to achieve differentiated regional environmental regulatory policies to further optimize the compensation effects of related enterprises' innovation [35–37]. According to different regional development levels, local governments in China should implement appropriate environmental regulations to achieve overall regional economic growth and green economic growth [38–42]. The heterogeneity of cities should be fully considered, the diversified development of industries within cities should be promoted, and differentiated environmental protection policies should be formulated. While promoting the general development of digitalization in an all-round way, digital investment in the eastern region and peripheral cities should be increased. Moreover, the digitalization of different industries in different cities shows great differences, and differentiated industry innovation policies are formulated according to the characteristics of different industries [43–45].

(2) Increase digital application and empower intelligent environmental governance. Under the reality that digital applications can strengthen the implementation of government policies, the Chinese government should increase investment in digital technologies such as the Internet and cloud computing, replace old existing data resource platforms, and introduce digital platforms for intelligent data collection and sharing [46–48]. The application of 5G, big data, and artificial intelligence should be added to simulation applications in data governance decision-making and emission reduction measures to promote the construction of Digital China [49,50]. The Chinese government should build a scientific decision-making mechanism based on big data resources so that environmental regulation policies can be implemented intelligently and transparently, and consolidate the dividend advantages of this policy system. Increase investment in digital applications, expand the construction of digital application scenarios in various fields such as transportation, finance, commerce, logistics, education, medical care, and elderly care, and improve the contribution of digital, networked, and intelligent technologies in green innovation [51–53]. Make use of the functional role of digitalization in big data, data mining, data analysis, etc., focus on solving problems such as digital application threshold and "digital divide" in the process of technological innovation, and give full play to the role of digitalization in enabling urban green innovation and intelligence.

(3) Strengthen the technological innovation system and enhance green efficiency. Technological progress is an important means to achieve a win–win situation for economic growth and environmental protection. At present, China's green innovation field still encounters many obstacles, and the ideological concepts and institutional mechanisms that restrict the development of China's green innovation still exist. Therefore, it is necessary to strengthen the establishment of a sound technological innovation system, adhere to the concept of innovation-driven development, develop and use green energy, and gradually establish a green production system [54]. Strengthen the direction of green technology innovation to improve regional green efficiency and eliminate institutional barriers to green innovation in the region. Chinese enterprises need to rely on the advancement of environmental protection technology to effectively control the discharge of wastewater, waste gas, and other pollutants. More importantly, in the future, the focus of eliminating ineffective supply, reducing the input of production factors, turning old into new ones, and realizing green production lies in technological progress. The innovation and application of China's green environmental protection technologies is inseparable from increased science and technology investment. Therefore, it is necessary to rationally design environmental regulations and policies to change the cost–benefit ratio of local governments, enterprises, and individuals in China, and increase the use of green technologies through a combination of active introduction and independent development.

(4) Upgrade the industrial structure and change the development concept. The Chinese government must change its previous development philosophy centered on GDP growth, adhere to the green economy development philosophy of protecting in development and developing in protection, and realize the benign interaction between environmental protection and economic growth. When high-level human capital flows into cities with high regional development levels, upgrade the local industrial structure to match it, and at the same time focus on the development of tertiary industries and green industries with low pollution and high economic benefits.

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