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Environmental regulation, industrial transformation, and green economy development

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Background: Green development, which is crucial because of the escalating ecological and environmental issues, is largely driven by industrial transformation and environmental legislation.

Purpose: The paper aims to examine the combined effects of environmental regulations and industrial change on the green economy, based on their separate effects.

Methods: We use a fixed-effects regression on panel data covering 30 provinces in China in 2010–2020.

Results: We reach the following conclusions: environmental regulations and rationalization of the industrial structure both support growth in the green economy, but advancement in the industrial structure hinders it. The combined effect of environmental regulations and advancement and rationalization in the industrial structure has a significantly positive impact on growth in the green economy; it is most pronounced in regions with higher resource endowments and economic development.

Discussion: By providing specific empirical facts, this study clarifies the effects of industrial transformation and environmental regulations on growth in the green economy, contributing to enriching the literature and helping to pave the way to sustainable development.

KEYWORDS

advanced industrial structure, environmental regulation, green economic development, rationalization of the industrial structure, economic growth

1 Introduction

The rapid advancement of industrialization and urbanization has enabled economic development and prosperity. However, the traditional economic model, which prioritizes growth over environmental concerns, at a cost of resource depletion, climate change, and pollution, is no longer viable. Emerging countries in the process of industrialization are raising the priority of environmental governance and seeking a balance between economic growth and environmental protection (Jiang et al., 2024). As a result, countries have increased their interest in forming a green economy—a new development paradigm that focuses on environmental balance, efficiency, and sustainability.

Environmental legislation significantly impacts green economic development, which is a crucial instrument for monitoring and improving environmental quality. To minimize

resource waste and environmental pollution and to achieve coordination between economic development and environmental protection, governments are implementing social regulations—which comprise government intervention and restrictions on economic activities through legal and administrative means—rather than environmental regulations (Yang et al., 2021; Chen et al., 2022). No consensus has been achieved in the literature about the relationship between environmental regulations and green economic development, although different environmental regulations have diverse effects. Some studies find that they have a significantly linear relationship and that environmental regulations can facilitate growth in the green economy (Bartolacci et al., 2019; Gong and Zhang, 2020). However, other studies argue that environmental regulations drive up business costs and impede growth in the green economy (Kolstad and Xing, 2002; Ambec et al., 2013; Wang and Li, 2021). Wang and Shen (2016) and Li et al. (2020) find that the relationship is nonlinear: that the impact of environmental regulations on efficiency in the green economy initially has a facilitating effect but, as its intensity increases, the impact eventually becomes inhibiting. Furthermore, some papers reveal that advancements in technology, the industrial structure, and other areas demonstrate the influence of environmental regulations on growth in the green economy (Fan and Sun, 2020; Yin and Gu, 2020).

Industrial transformation can optimize resource allocation, enhance resource utilization efficiency, improve the environment and ecology, and support growth in the green economy (Dao et al., 2024). It is a crucial strategy for shifting the mode of economic growth (Jin and Li, 2013; Peng and Sun, 2015; Mikhno et al., 2021; Wang et al., 2024). Prior research on the effect of industrial transformation on growth in green economies employs three main approaches. First, industrial transformation is used as the main explanatory variable for directly examining its influence on green economic development (Liu and Wei, 2020; Tang and Wei, 2024). The second approach involves using industrial transformation as a mediating variable to examine the effects of technological innovation, environmental regulations, and government behavior on green economic development (Meng and Shao, 2020; Yang et al., 2022). Lastly, industrial transformation is selected as a control variable to examine the effect of other factors on growth in the green economy (Wang, 2023; Zhou and Li, 2023).

The industrial, scientific, and technological revolutions have reached a new stage, becoming major factors in China's economic growth and transformation. However, whether this industrial transformation will improve the environment is still undetermined (Sun et al., 2020). Pollution might be transferred and spread along with industrial development (Ouyang et al., 2020). The "pollution haven" theory proposed by Copeland and Scott (1994) holds that geographic variation in environmental laws causes polluting companies to relocate to regions with laxer laws, which in turn affects local economic growth (Kheder and Zugravu, 2012; Solarin et al., 2017; Li et al., 2021; Zhao Y. et al., 2021). Does green economic development benefit from the combined effects of environmental regulations and industrial change? The impact of environmental regulations, industrial change, and a combination of them on development of a green economy is, thus, the research question addressed in this study.

Enacting environmental regulations and transforming the industrial sector are crucial to achieving sustainable and high-quality development. Environmental regulations protect the environment in which people live, industrial transformation drives economic growth, and green economic development facilitates the successful combination of social development and environmental protection (Zhang et al., 2024). Therefore, studying the connection among industrial transformation, environmental legislation, and green economic growth is important. This study reveals the connection between environmental regulations and industrial transformation to explain their synergistic effects on the green economy. Furthermore, the paper takes into account the variations in resource endowments, industrial foundation, and economic development in different regions in China. It explores the heterogeneous relationship between variables such as the more rapid economic development in eastern China, which is dominated by the service industry and supports green economic growth, whereas the governments in central and western China are more focused on developing their urban and rural economies, which have not yet prioritized the green economy.

The paper makes two potential contributions to the literature. First, in contrast to prior studies, this paper carefully examines the interaction between environmental regulations and industrial transformation as well as their synergistic effects on green economic growth to explain China's path to sustainable development. Second, it considers the different impacts of resource endowment and economic development on the interaction effect between them on green economic development. This demonstrates the regional diversity and makes specific recommendations that enhance the applicability of our findings.

Following this introduction, the paper is organized as follows. Section 2 lays out our theoretical analysis and describes our hypotheses. Section 3 describes the variables and the model. Section 4 gives our empirical findings from the baseline, robustness, and heterogeneity tests. Section 5 offers some recommendations and a summary. The research framework of the whole paper is shown in Figure 1 and the framework of the theoretical analysis is shown in Figure 2.

2 Theoretical analysis

2.1 Impact of environmental regulation on the development of a green economy

Environmental regulation embodies the government's development of appropriate policies for addressing market failures that lead to negative externalities impacting the environment (Stern, 2022). It also involves the full mobilization of social forces on all fronts and the adoption of direct or indirect means of regulating micro-entities, all of which can promote coordinated development of environmental protection and the economy (Zhang, 2023). From the perspective of dynamic competition, the Porter hypothesis states that pertinent environmental regulations will accelerate technological innovation. This will result in lower costs and higher

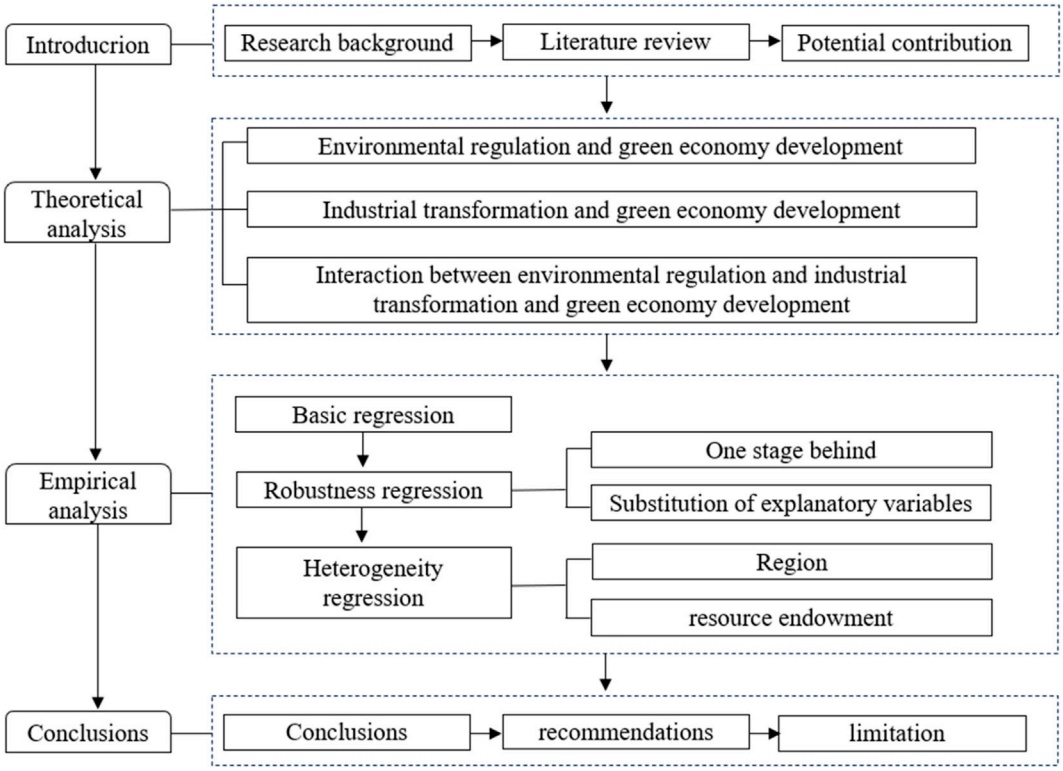

FIGURE 1
Flowchart of the research framework.

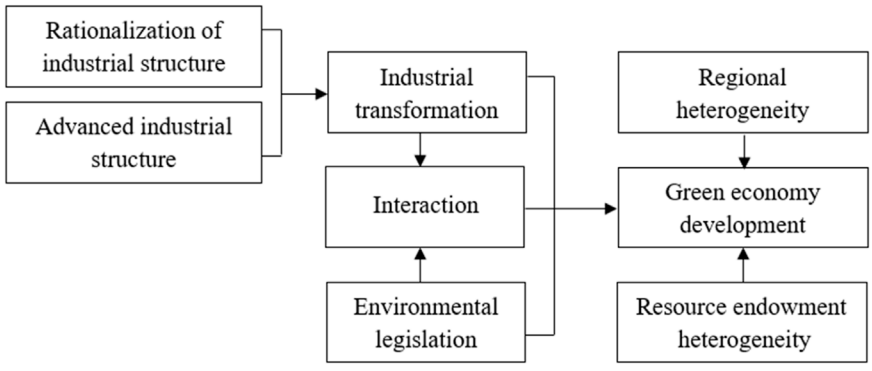

FIGURE 2
Flowchart of the theoretical mechanism.

productivity, which will enhance a country's competitive advantage and, in the end, coordinate environmental protection with economic and social development (Porter and Van der Linde, 1995). As a result, technological innovation with environmental regulation will encourage ongoing optimization of the industrial structure, which will support growth in the green economy. The policy and implementation framework for environmental regulations in China is continually developing, and, at the same time, technological innovation across all domains is increasing. As a result, the impact of environmental regulations on innovation is increasingly apparent.

Hypothesis 1. The growth of the green economy is facilitated by environmental legislation.

2.2 Impact of industrial transformation on green economic development

The primary manifestations of industrial transformation are efficiency gains and adjustments in the industrial structure. The influence of industrial transformation on growth in the green

economy comes from having an advanced and rational industrial structure.

2.2.1 Rationalization of the industrial structure

Rationalization of the industrial structure means that, as the economy develops, the allocation of their factors of production in the various industrial sectors change in response to changes in the structure of demand, encouraging the rational use of resources (Chang et al., 2023; Huang, 2022). Increased rationalization in the industrial structure not only encourages the flow of excess resources to resource-poor sectors, thereby promoting an efficient allocation of resources among industries but also helps reduce resource waste and environmental pollution (Zhao K. et al., 2021). This transition from extensive to intensive economic growth (Li et al., 2024) creates a "win-win" scenario in which environmental protection and economic growth both benefit, ultimately promoting green economic development.

Hypothesis 2. Rationalization of the industrial structure contributes to development in the green economy.

2.2.2 Advanced industrial structure

An advanced industrial structure is an industrial configuration enhanced by labor, capital, technology, and knowledge intensity (Song et al., 2022; Yin et al., 2024). The development of an advanced industrial structure has two primary effects. First, it shifts the focus of development to the manufacturing and service sectors, with a gradual corresponding migration of the workforce. Second, it encourages the rational allocation of production factors, thereby improving resource utilization efficiency, making the distribution of labor and materials efficient, and promoting development in the green economy. However, the relationship between an advanced industrial structure and growth in the green economy is not straightforward. In highly industrialized regions, the advanced industrial structure can foster rapid growth in services, further advancing development in the green economy. Nonetheless, in China, regional differences in economic development mean that the industrial structure remains unbalanced, and most areas will remain dominated by manufacturing for the foreseeable future. Therefore, it is premature to "de-industrialize" and shift the development focus across the board solely to services. Such a shift could lead to resource mismatches, constraints on industrial expansion, and an economic downturn, all of which would be detrimental to growth in the green economy.

Hypothesis 3a. An advanced industrial structure contributes to economic development.

Hypothesis 3b. Advanced industrial structure inhibits economic development.

2.3 The interaction effect of environmental regulation and industrial transformation on development of a green economy

Strict environmental regulations during an industrial transformation can lead to a scenario characterized by "survival of the fittest" (Ansari and Holz, 2020). Environmental regulations often involve sewage charges or company investments in pollution control which increase business costs and impact industrial transformation (Shen and Zhang, 2022). Government mandates requiring highly polluting enterprises to reduce their emissions can impede their ability to expand in the short term. However, these mandates also accelerate growth in the service sector and force an industry to pivot to a service orientation. Small and medium-size enterprises (SMEs) are particularly affected by deepening in industrial transformation, as they may be unable to afford the high cost of compliance with strict environmental regulations. They may ultimately be forced out of the market (Despoudi et al., 2023). Expansion in the service sector will spur more creative innovation and creation of environmentally friendly products, which will boost the efficiency of resource allocation and collaboration (Yang et al., 2024) and support a green economy. The frequency of environmental monitoring and the strictness of environmental legislation imposes significant regulatory pressure on businesses, which can contribute to growth in the green economy. Additionally, Chinese regions have differences in resource endowment and economic development levels, leading to variation in the strength of environmental regulations and the degree of industrial transformation. These regional variations also impact the degree of green economic development.

Hypothesis 4. The interaction effect of environmental regulation and industrial transformation can effectively promote development in a green economy.

Hypothesis 5. The impact of the interaction effect of industrial transformation and environmental regulation on development in a green economy varies depending on resource endowment and geography.

3 Research design

3.1 Model setting

The explanatory variable is the level of development of the green economy, and the main explanatory variables are environmental regulation, rationalization of the industrial structure, and having an advanced industrial structure. In order to estimate the impact of environmental regulations and industrial transformation on the development of the green economy, combined with the previous analysis, we construct a regression model as the following Equations 1–4:

$$GDI_{it} = \alpha_0 + \alpha_1 ER_{it} + \alpha_2 CV_{it} + \varepsilon_{it} \quad (1)$$

$$GDI_{it} = \beta_0 + \beta_1 TL_{it} + \beta_2 CV_{it} + \varepsilon_{it} \quad (2)$$

$$GDI_{it} = \gamma_0 + \gamma_1 TS_{it} + \gamma_2 CV_{it} + \varepsilon_{it} \quad (3)$$

$$GDI_{it} = \varphi_0 + \varphi_1 ER_{it} + \varphi_2 TL_{it} + \varphi_3 TS_{it} + \varphi_4 CV_{it} + \varepsilon_{it} \quad (4)$$

where i is a region, and t is the time. CV means the control variables: population density, education level, urbanization level, degree of foreign direct investment, and government intervention. TL is rationalization of the industrial structure, TS is an advanced

industrial structure, and *ER* is the level of environmental regulation. ε is a random disturbance term.

Building on the analysis by Tang et al. (2014), we next analyze the impact of environmental regulations and industrial transformation on the development of a green economy and their joint impact. We introduce the main explanatory variables: interaction terms between environmental regulations and an advanced industrial structure as well as between environmental regulations and rationalization of the industrial structure, as the following Equations 5, 6:

$$GDI_{it} = \delta_0 + \delta_1 ER_{it} \times TL_{it} + \delta_2 CV_{it} + \varepsilon_{it} \quad (5)$$

$$GDI_{it} = \lambda_0 + \lambda_1 ER_{it} \times TS_{it} + \lambda_2 CV_{it} + \varepsilon_{it} \quad (6)$$

3.2 Selection of variables

3.2.1 Explanatory variables

The explanatory variable in this paper is *green economic development*. The two main types of indicators used to measure green economic development currently employed by scholars are individual and comprehensive. The evaluation system to assess green economic development in this paper comprises nine indicators: gross domestic product (GDP), GDP *per capita*, internal funding for R&D, the number of patents awarded, total energy consumption as a share of GDP, total electricity consumption as a share of GDP, and emissions of industrial wastewater, sulfur dioxide (SO_2), and soot. These indicators are sorted into four dimensions (Hong, 2020): technological innovation, environmental pollution, energy consumption, and economic development. The measurement process entails standardizing the nine indicators to remove scale differences, performing time-series global principal component analysis using SPSS software, and determining an annual green economic development index (GDI) for every province.

3.2.2 Main explanatory variables

3.2.2.1 Environmental regulation (ER)

Effective environmental regulations are vital for reducing pollution, minimizing energy loss, protecting the environment, and encouraging local green economic development. Investment in industrial pollution control is the amount of money invested by the government in managing industrial solid waste, wastewater, exhaust gas, and other pollutants. Its magnitude represents the actual strength of environmental regulations (Wang and He, 2022; Zhao et al., 2023). The ratio of the total amount invested in industrial pollution control to the total value of industrial output is used to proxy for the level of environmental regulation; when this ratio is higher, more funding are used in industrial development for pollution control and emissions reduction, which will play a larger role in promoting growth in the green economy in a region.

3.2.2.2 Industrial transformation (INS)

The dynamic industrial transformation process is characterized by the rationalization and sophistication of the industrial structure. To measure them in this analysis, we follow Gan et al. (2011) and others.

We construct a Taylor's index, which measures the rationalization of industrial structure, as the following Equation 7:

$$TL = \sum_{i=1}^{3} \left(\frac{Y_i}{Y}\right) \ln\left(\frac{Y_i}{L_i} \Big/ \frac{Y}{L}\right) i = 1, 2, 3 \quad (7)$$

where Y is the value of production, L is the number of workers, and i means primary, secondary, and tertiary industry in China; they take values of 1–3. The rationality of the industrial structure increases as TL approaches 1.

The advanced industrial structure is proxied by the ratio of value added of tertiary industry to the value added of secondary industry, which is calculated as the following Equation 8:

$$TS = Y_3 / Y_2 \quad (8)$$

where Y_3 indicates the value added of tertiary industry, and Y_2 denotes the value added of secondary industry. Increases in *TS* mean that an industry is moving closer to being a tertiary industry, the economy is gradually shifting to being service oriented, and the industrial structure is changing.

3.2.3 Control variables

3.2.3.1 Population density (PD)

Population density reflects the distribution of population in a region. Rising population density helps to increase the supply and distribution of labor and this will drive economic development; however, it will create employment problems and resource shortages, which will impede development of a green economy. Hence, population density significantly impacts development of a green economy in both negative and positive ways. Following Zhou et al. (2023), we proxy population density by the population in a region at the end of the year.

3.2.3.2 Education level (EDU)

A higher education has a greater driving impact on technological innovation and plays a positive role in integral social development. Because education is positively correlated with the store of knowledge, which reflects the potential for technological progress, education also affects the development of a green economy. Following Jiao et al. (2013), we proxy the level of education by expenditure on local education as a share of GDP.

3.2.3.3 Urbanization level (US)

Following Chen et al. (2023), we use the region's urban population/total population to express the level of urbanization. Urbanization is beneficial for improvement in various types of infrastructure in the region, which promotes the redistribution of social resources and thus impacts the development of a green economy.

3.2.3.4 Level of foreign direct investment (FDI)

Following Ma and Xie (2023), we proxy the amount of FDI by actual foreign investment as a share of GDP. Foreign investment affects the development of green economies in two different ways. Although some foreign-funded businesses cannot bring cutting-edge products and technology to market and choose, instead, to establish energy-intensive, polluting factories that will harm the

TABLE 1 Descriptive statistics.

Variable	Variable label	Max	Min	Mean	S.D.
Level of green economic development	*GDI*	0.8794	0.1552	0.4897	0.1376
Environmental regulation	*ER*	0.5482	0.0512	0.2098	0.0959
Rationalization of industrial structure	*TL*	0.7770	0.0079	0.2114	0.1443
Advanced industrial structure	*TS*	5.2440	0.5270	1.2961	0.7194
Population density	*PD*	3923.9810	7.7945	467.4833	699.3683
Education level	*RS*	0.0907	0.1967	0.0398	0.0142
Urbanization level	*US*	0.8958	0.3380	0.5836	0.1253
Level of foreign direct investment	*FDI*	0.0796	0.0001	0.0197	0.0155
Government intervention	*GZ*	0.6430	0.1058	0.2480	0.1035

TABLE 2 The impact of environmental regulation and industrial transformation on green economic development.

Variable	Model (1)	Model (2)	Model (3)	Model (4)	Model (5)	Model (6)
ER	2.5867*** (4.2845)			2.4833*** (4.1759)		
TL		0.0800*** (2.9900)		0.0674*** (2.6026)		
TS			−0.0318** (−2.5674)	−0.0336*** (−2.8351)		
TL × *ER*					7.1528*** (4.7189)	
TS × *ER*						1.6031*** (3.5440)
PD	0.0005*** (6.1648)	0.0005*** (5.5788)	0.0005*** (6.0926)	0.0005*** (6.2119)	0.0005*** (6.2644)	0.0005*** (5.8156)
EDU	1.4320** (2.5717)	0.9472* (1.6982)	0.9402* (1.6778)	1.2679** (2.3212)	1.4436*** (2.6137)	1.3744** (2.4422)
US	0.2782** (2.2286)	0.2908** (2.2690)	0.0790 (0.5705)	0.1808 (1.3406)	0.3130** (2.5074)	0.2497** (1.9880)
FDI	0.2355 (1.2779)	0.3296* (1.7658)	0.3548* (1.8850)	0.3123* (1.7220)	0.3011* (1.6509)	0.2309 (1.2381)
GZ	−0.6484*** (−7.2930)	−0.6127*** (−6.7910)	−0.5891*** (−6.4344)	−0.6002*** (−6.8202)	−0.6496*** (−7.3548)	−0.6675*** (−7.3828)
Observations	330	330	330	330	330	330
R2	0.871	0.867	0.866	0.878	0.873	0.869

Note: *t*-values are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

environment and hinder growth in regional green economies, others can obtain capital and technology that will boost competitiveness, enhance the environment, and raise the level of green economic development. The level of foreign investment is also an important factor that affects growth of a green economy.

3.2.3.5 Government intervention (GZ)

Following Hu et al. (2023), we proxy for government intervention using GDP/regional financial expenditure. The survival and growth of companies is impacted by many government policies, which have a significant effect on economic development.

3.3 Data sources and descriptive statistics

Based on the availability of data, we use sample data on 30 provinces in China (excluding Tibet, Hong Kong, and Macao) from 2010 to 2020, which are obtained from the National Bureau of Statistics, *China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, China Urban Statistical Yearbook*, and the annual statistical yearbooks of each province; some missing values are handled using interpolation. The descriptive statistics of the variables are listed in Table 1.

4 Results and analysis

4.1 Analysis of baseline regression results

Fixed-effects estimation and random-effects estimation are popular techniques for evaluating panel data. The *p*-value of Models (1)–(6) is less than 0.01, hence the hypothesis that the "random-effects model is the correct model" is rejected (Hausman test results), which suggests that a fixed-effects model is appropriate for the estimation of all six models.

Table 2 shows that environmental regulation and industrial structure rationalization make a major contribution to the degree

of green economic development, supporting H1 and H2. In Model (3), the coefficient of the influence of an advanced industrial structure on growth in the green economy is −0.318, and it is significant at the 5% level. This suggests that the development of an advanced industrial structure hinders growth in the green economy, confirming H3b. This could be because of issues due to uneven development in the industrial structure across regions and the stark differences between them, as well as the difficulty in achieving the structural dividend from the shift in the industrial structure from manufacturing to services, which is detrimental for growth in the green economy. The results indicate that although the advancement in the industrial structure has significantly negative coefficients, the environmental regulation and rationalization in the industrial structure have significantly positive coefficients at the 1% level. This suggests that the development of China's green economy is aided by ongoing improvements in environmental regulations and the industrial structure, but that the advancement in the industrial structure due to regional differences and other issues does not help develop the green economy.

The influence of environmental regulation on growth in the green economy through industrial transformation is shown by the interaction terms between environmental regulation and advanced industrial structure and between environmental regulation and a rationalized industrial structure. Development in the green economy is positively aided by environmental regulation through the advancement and rationalization of the industrial structure, as demonstrated by the results of Models (5) and (6) in Table 2, in which the coefficients of the interaction terms are both significantly positive at 7.1528 and 1.6031, respectively. This confirms H4. The coefficient of the interaction term between environmental regulation and advancement in the industrial structure is 1.6031, whereas the coefficient for the interaction term between environmental regulation and rationalization of the industrial structure is 7.1528. This means that environmental regulation supports the development of a green economy more clearly through rationalization of the industrial structure than through advancement in the industrial structure. Furthermore, a comparison of Models (2)–(4) and (5)–(6) shows that the interaction term between environmental regulation and advancement in the industrial structure weakens the impact of advancement in the industrial structure on green economic development. However, the interaction term between environmental regulation and rationalization of the industrial structure plays a major role in promoting the effect of rationalization of the industrial structure and green economic development.

Among the control variables, population density and rising population have significantly positive coefficients, meaning that the marginal speed of green economic development is positive in areas with more highly developed education and population concentration. This might be because these factors improve the supply and distribution of labor, which improves resource allocation efficiency. Additionally, rising education levels and a more knowledgeable workforce also contribute to technological advancement and overall social development, both of which support green economic development. The degree of regional urbanization in China is still uneven; foreign investment has not brought cutting-edge technology and experience, and no discernible relationship is found between the level of urbanization and the level of FDI and growth in the green economy. The coefficient of government intervention in the development of the green economy is significantly negative. The government takes initiatives to modify the industrial structure of each location in order to achieve sustainable development. As part of this process, some traditional or inefficient factors of production from developed regions shift to underdeveloped areas, which transfers pollution and negative externalities. It has not yet helped to advance growth in the green economy.

4.2 Robustness tests

We use two approaches in performing robustness tests. First, we use latenctest for one lag. The interaction terms for environmental regulation, rationalization of the industrial structure, advancement in the industrial structure, and environmental regulation and industrial structure rationalization and advancement are lagged by one period, following Zhang et al. (2011) and Zhao et al. (2019), and the model is regressed again because the implementation effect of environmental regulation policy and industrial transformation has a certain lag. Second, we the main explanatory factors, following Liu and He (2021), substituting the percentage of investment in industrial pollution control in manufacturing for environmental regulation. The results for the two methods are displayed in Table 3, demonstrating that advancement in the industrial structure inhibits growth in the green economy. At the same time, environmental regulation can support it through advancement in the green economy through rationalization of the industrial structure and advancement in the industrial structure, in which the former has a greater impact than the latter. As a result, our initial findings are shown to be robust.

4.3 Heterogeneity analysis

4.3.1 Analysis of regional heterogeneity

The 30 provinces are split into eastern and central-western areas for analysis based on the characteristics of each province's location and degree of regional economic growth (Zhang and Chen, 2020). The findings are in Table 4. They show that the eastern region has significantly higher coefficients for rationalization in the industrial structure and environmental regulation than the central and western regions, although both are significantly positive from the perspective of rationalization in the industrial structure. The reason for this result is that development in the eastern region is dominated by the service industry, which is known for its high levels of technology and low levels of pollution, making it a powerful force for growth in the green economy. Under the development of certain national strategies, the western and central regions have seen an improvement in resource utilization and economic growth. However, there is still a significantly different in terms of regional economic development compared to the eastern region, and the strength of environmental regulations is relatively weak, infrastructure construction is relatively underdeveloped, and there is a lack of skilled workers. Therefore, the promotion of green economic development through the rationalization of industrial structure by environmental regulations in t the central and western regions is less than that the eastern region. Environmental regulation can help foster growth in the green

TABLE 3 Robustness tests.

Variable	One-lagged test		Replacement of the main explanatory variables			
	Model (4)	Model (5)	Model (6)	Model (4)	Model (5)	Model (6)
ERN				2.6749*** (2.8098)		
TL				0.0730*** (2.7808)		
TS				−0.0299** (−2.4822)		
ER1	1.7668*** (3.0028)					
TL1	0.0701** (2.4698)					
TS1	−0.0254** (−1.9839)					
ERN × TL					8.8756*** (3.7365)	
ERN × TS						1.7414** (2.4705)
(ER × TL)1		5.5822*** (3.6508)				
(ER × TS)1			1.1187** (2.4831)			
Control variables	yes	yes	yes	yes	yes	yes
Observations	330	330	330	330	330	330
R2	0.871	0.868	0.864	0.874	0.869	0.866

Note: *t*-values are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

TABLE 4 Heterogeneity analysis.

	Regional heterogeneity				Resource endowment heterogeneity			
	Model (5)		Model (6)		Model (5)		Model (6)	
	East	Central/West	East	Central/West	Resource based	Non−resource based	Resource based	Non−resource based
TL x ER	37.097***	4.109***			5.069*	7.589***		
	(−3.86)	(−2.92)			(−1.78)	(−4.01)		
TS×ER			2.172***	1.057**			1.517	1.702***
			(−2.88)	(−2.00)			(−1.56)	(−3.22)
Control variables	yes	yes	yes	yes	yes	Yes	yes	yes
Observations	132	198	132	198	121	209	121	209
R2	0.874	0.864	0.867	0.861	0.842	0.861	0.841	0.856

Note: *t*-values are in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

economy by rationalizing the industrial structure in both the eastern and central regions. However, environmental regulation is less significant in the central and western regions because environmental regulation tends to be stronger in the eastern region and weaker in the central and western regions, which leads to the relocation of highly polluting enterprises to the central and western regions.

4.3.2 Analysis of resource endowment heterogeneity

China is a large country with diverse environmental regulations, resource endowments, and levels of green economic development in each province and region. These differences are particularly noticeable between regions whose economies are resource based and those whose economies are not resource based. Based on these differences, we divide the 30 provinces into two groups: the first group comprises resource-based regions: Xinjiang, Shaanxi, Yunnan, Guizhou, Sichuan, Heilongjiang, Jilin, Liaoning, Inner Mongolia, Shanxi, and Hebei; and the second group consists of the other regions, which do not have resource-based economies (Zhang et al., 2022). The results in Table 4 show that environmental regulation in resource-based regions positively encourages growth in the green economy through industrial transformation. However, the significance level is low, suggesting that environmental regulation encourages some resource factors to be invested in clean industry, which has some bearing on growth in the regional industry. The relationship between the development of the green economy and industrial transformation is also not readily apparent. However, the

results demonstrate that environmental regulation is more appropriate in non–resource-based regions. Environmental regulation through rationalization and advancement in the industrial structure has a positive impact on growth in the green economy, and both exceed the 1% significance level, suggesting that environmental regulation plays a more significant role in non–resource-based regions. Therefore, H5 is confirmed: the synergistic effect of environmental regulation and industrial transformation is more significant in the eastern region and non–resource-based regions, which promotes development in regional green economies to varying degrees. The interactive effect of environmental regulation and industrial transformation on green economic development varies depending on the level of economic development and resource endowment.

5 Conclusions and recommendations

This paper analyzes panel data on 30 Chinese provinces from 2010 to 2020, using a fixed-effects model, obtaining the following findings. First, development of a green economy is strongly aided by environmental regulations and rationalization in the industrial structure; however, advancement in the industrial structure has a detrimental influence on this growth. Second, green economic development can be positively impacted by the relationship between optimization in the industrial structure and environmental legislation. Environmental regulations and rationalization of the industrial structure work together to mitigate the detrimental effects of rationalization in the industrial structure on green economic growth and to further it. Third, different regions have varying levels of economic development and resource endowment and, therefore, are affected differently by the interactive effect environmental regulation and rationalization in the industrial structure; the effect is more pronounced in the eastern region and non–resource-based regions.

Our findings lead to the following policy and practical implications on how to promote growth in the green economy and achieve sustainable development. First, environmental regulation policies and regulations should be enhanced, the implementation of environmental regulations needs to increase, the bar should be raised for the development of environmental infrastructure, the relevant governance structure needs to improve, the system of subsidies for the development of green enterprise transformations should be enhanced, the capacity for independent innovation and research and development need to continuously improve; and the transformation of industry into a low-carbon, clean sector requires more support. Second, different environmental regulation strategies should be implemented based on the unique environmental conditions of each region in order for the "invisible hand" theory to be realized, local industry transformation should be supported at the same time that the demonstration effect is seen, and the development and optimization of neighboring regions' industrial structure need to be encouraged. Furthermore, environmental regulations must be implemented gradually and methodically while the industrial structure is adjusted; the degree of environmental regulation should not be raised arbitrarily. Third, in order to promote coordinated regional development, policies related to industrial transformation and development should be formulated in consideration of the existing state of regional development, taking into account local conditions. It is crucial for the process of advanced industrial structure to advance slowly and methodically in regions with comparatively low levels of economic growth, rather than rashly and prematurely "de-industrializing" them. More economically developed areas should play a radiation-driven role, assisting in the growth of surrounding regions, and supporting the development of the economically backward regions.

Our study has some limitations. First, green economic development is a broad concept that encompasses social, environmental, and economic dimensions. The indicators of green economic development constructed in this paper might not provide a thorough and exhaustive overview of its implications, so the results of our empirical research might be biased. Future studies should further standardize the indicators for evaluating green economic development. Second, we use a single empirical model, but it may not be possible to fully capture the complex relationship between environmental regulation and industrial transformation and their synergistic effects on green economic development in this way; better results could be obtained through greater diversification of the research methodology. Third, our sample consists of provincial panel data based on data availability, so we could not expand the scope of the study to include municipal or county-level data; however, the needs and circumstances within various regions differ, so subsequent research is needed when that data becomes available, in order to obtain more targeted results.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

HS: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing–original draft. QP: Conceptualization, Methodology, Resources, Validation, Visualization, Writing–review and editing. FZ: Funding acquisition, Writing–review and editing. WW: Funding acquisition, Writing–review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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