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Study on the Dynamic Analysis of the Evolutionary Game and Influence Effect of Green Taxation in Promoting the Development of New Energy Industry

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Abstract: The development of China's new energy industry has accelerated, significantly advancing the country's progress toward achieving "carbon neutrality" and "carbon peak". In this context, green tax serves as a powerful catalyst for the growth of the new energy sector. Taking into account the heterogeneity of enterprises, this paper constructs a dynamic evolution model involving the "government, local enterprises, and foreign enterprises" to elucidate the decision-making mechanisms of traditional energy enterprises in their transition to new energy, driven by green tax incentives. Using corporate financial report data from the Wind database and energy and economic data from Chinese provinces from 2016 to 2021, this study empirically examines the impact of green tax on the development of the new energy industry. The findings indicate that implementing a green tax system can effectively promote the regional growth of the new energy sector. This positive effect remains robust even after accounting for intrinsic factors and employing various validation tools. Furthermore, a regional comparison reveals that the positive impact of environmental taxes is more pronounced in the western regions of China than in the more industrially developed eastern and central regions. This suggests that environmental taxes contribute to reducing disparities in the development of the new energy industry across provinces. In conclusion, this paper confirms that green tax significantly promotes the development of China's new energy industry. It holds practical significance in fostering vigorous growth in this sector while also helping to narrow regional industrial development gaps through tax policy.

Keywords: green tax, new energy industry, evolutionary dynamic modeling

1. Introduction

Green tax policies, as a tool to guide market behavior, play a crucial role in promoting the transition from traditional to new energy sources. They not only provide policy support but also help regulate pollution and foster green innovation. Achieving the "double carbon" goal—reducing carbon emissions within a specified period—is the strategic direction of China's ecological civilization construction [1]. Promoting the development of new energy industries through green taxes is considered an effective pathway to carbon neutrality [2]. To ensure that green taxes effectively incentivize energy transition, it is essential to understand the transition behaviors of enterprises under the influence of green taxes, clarify their micro-mechanisms, and scientifically assess the effectiveness and efficiency of the policies. Green taxes inherit the function of traditional taxes while incorporating environmental management elements [3]. They deepen the traditional tax function and complement environmental policies. From a traditional taxation perspective, green taxes reduce the tax burden on environmentally friendly enterprises, encouraging innovative investments by optimizing resource allocation and directing funds to greener areas. Although existing studies have examined the impact of green taxes on corporate technological innovation from various angles, further clarification is needed regarding the micro-mechanisms by which green taxes facilitate the transition of traditional energy firms to new energy. Simultaneously, they increase the costs for polluting enterprises, pushing them toward green development. From an environmental management perspective, green taxes may raise operational costs for firms, potentially limiting their investment in innovation. However, they might also stimulate innovative reforms to offset increased costs through technological progress [4]. Therefore, the impact of green taxes on firms' technological innovation carries some uncertainty. Overall, green taxes influence the new energy industry through tax support and risk diversification for green firms and cost constraints and transformation pressures for polluting firms [5]. Although existing studies have examined the impact of green taxes on corporate technological innovation from various angles, further clarification is needed regarding the micro-mechanisms by which green taxes facilitate the transition of traditional energy firms to new energy. Most of the current literature focuses on macro-level analyses of tax data, with scholars providing empirical evaluations of enterprise operating costs and investment levels based on the green tax amounts announced by the State Administration of Taxation or enacted green tax policies. However, they often fail to rigorously explore how green taxes support the development of emerging industries through microscopic mathematical and theoretical mechanisms. Additionally, determining the conditions under which this positive impact reaches its optimal effect is a topic that requires further investigation. There is also a lack of clarity in describing the

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new energy industry, as most studies emphasize sectors like new energy power generation and generator installation—such as wind, hydro, and nuclear energy—while neglecting the growth of new energy enterprises. This study shifts focus to the pivotal role played by these enterprises in measuring the development level of the new energy industry.

This paper compares the mechanisms of green tax and green finance on enterprise impact effects, accounting for enterprise heterogeneity. It constructs a tripartite evolutionary game model involving the government, local enterprises, and foreign enterprises to analyze the micro-mechanisms of differentiated green taxes. Through mathematical deduction, it is demonstrated that when enterprises in both regions achieve economic benefit equilibrium—that is, when neither party's decision-making diminishes the economic benefits of the other while improving its own—the green tax policy can motivate enterprises to transition to the new energy industry spontaneously. This result provides detailed and rigorous proof that green tax policies can promote new energy industry development without relying on subjective macro-policy evaluations. It offers a mathematical derivation mechanism for understanding the role of green taxes in fostering green industry growth.

For measuring the development level of the new energy industry, this study calculates the development index for each region using financial report data from new energy-listed companies in the Wind database, along with China's energy and economic development data from 2016 to 2019. A fixed effects model is employed to analyze the policy's mechanisms, clarify the actual effects of green taxes on new energy industry development, and further explore the differential role of geographic location factors. This approach provides a fresh perspective on understanding the heterogeneous outcomes of green taxes.

2. Literature Review

The direct impact and spatial spillover effects of green tax policy on the development of the new energy industry represent a cutting-edge research area, particularly in relation to global climate change and environmental protection. Scholars, both domestic and international, have conducted in-depth literature reviews to systematically integrate and summarize relevant research findings, aiming to gain a comprehensive understanding of the mechanisms through which green tax policy influences the new energy industry.

Wang and Ma [6] empirically analyzed the positive effect of digital inclusive finance on limiting carbon dioxide emissions, demonstrating that digital inclusive finance can promote green innovation in enterprises, thereby reducing carbon emissions. In the energy sector, Wang et al. [7] also investigated how major energy-producing regions can achieve peak carbon emissions, using the open STIRPAT model to measure carbon emissions levels in high-energy-producing regions at their peak. This study provides a reference value for China in managing its energy economic transformation. In policy research, Jastrzębski and Kula [8] emphasized the importance of various policy tools, including green tax policy, in the development of the new energy industry. Similarly, Xu et al. [9] explored the role of green tax policy in the transition to clean technology, highlighting its contribution to the upgrading and transformation of the new energy industry. Against the backdrop of the "dual carbon" target, Lu et al. [10] summarized recent research on using taxes to promote climate action globally and provided insights into how green tax policy can support the development of the new energy industry. Zhao et al. [11] analyzed the spatial spillover effects of green tax policy in China and found that these effects vary across different regions, influencing the development of the new energy industry unevenly. Huq et al. [12] showed that green taxes can increase market share for green enterprises, creating more business and employment opportunities, thus promoting a low-carbon economy. With the rise of e-commerce, Wen et al. [13] studied the impact of environmental regulation on green innovation in cross-border e-commerce. Their analysis, using the Threshold Effects Modeling, concluded that increased environmental regulation significantly promotes green innovation, with many merchants beginning to pursue greener packaging materials. From a pollution governance perspective, Remler [14] suggested that governments should evaluate policy measures related to environmental management, with green taxes serving as a key tool. Powell et al. [15] observed that the taxes enterprises incur due to pollution far exceed their capital investments in pollution management, which motivates them to pursue technological innovation to reduce their tax burden [16].

Despite these contributions, there are still shortcomings in existing research on green tax policy and its impact on the development of the new energy industry. First, although studies have identified the direct impact and spatial spillover effects of green tax policy, its underlying mechanisms require deeper exploration. Second, given the differences in industrial structures and policy environments across regions, the effects of green tax policies may vary, necessitating more region-specific studies.

In the context of the "double carbon" goal, scholars have extensively studied the impacts of digital finance and energy transition on emissions reduction and have emphasized the critical role of the new energy industry in achieving carbon peaks. Research in taxation has explored the impact of green taxes on corporate technological innovation from various perspectives. However, the micro-mechanisms by which green taxes promote the transition of traditional energy enterprises to new energy enterprises remain unclear. Existing literature predominantly focuses on macro-level analyses of tax data, using green tax policies and amounts announced by the State Administration of Taxation (SAT) to assess the operating costs and investment levels of enterprises. Yet, these studies often neglect to employ micro-mathematical mechanisms to thoroughly analyze the actual promotion effects of green taxes on emerging industries and the conditions under which they achieve optimal results. Additionally, research on the new energy industry tends to be vague, concentrating mostly on power generation industries such as wind, hydro, and nuclear energy, while overlooking the growing significance of new energy enterprises. This study will specifically focus on the crucial role that new energy enterprises play in measuring the development level of the new energy industry.

3. Methodology

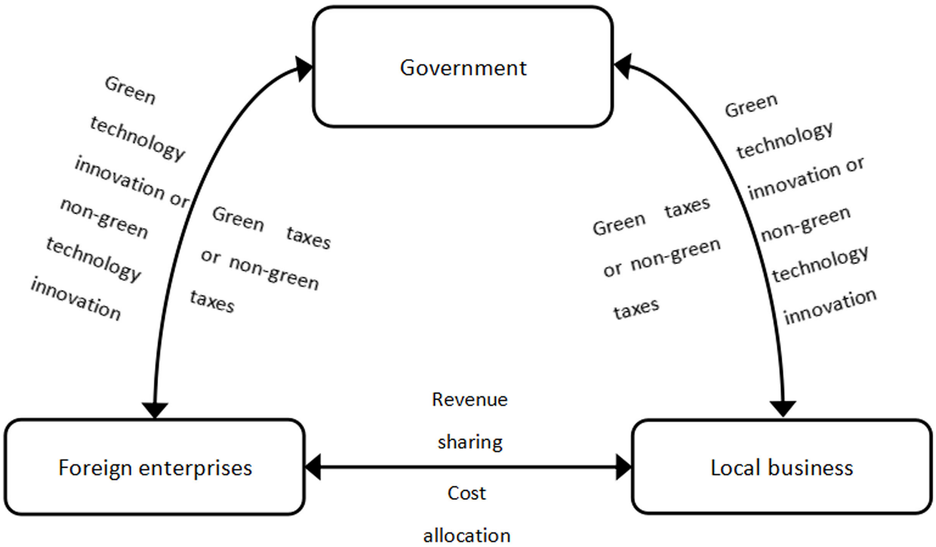
3.1. Model assumptions

According to the path of dynamic analysis of the evolutionary game, I constructed a three-party game model of 'government-local enterprises-foreign enterprises', as shown in Figure 1. the government levies a green tax that affects the profits of enterprises, and enterprises avoid the tax and pass on the cost through the transformation of new energy industry. The model also needs to fulfil the following assumptions:

Assumption 1: The model contains three different types of participants, and the set Ω is used to represent all game participants. Together, these three types of participants form a complete game system [17]. A key difference between evolutionary game theory and traditional game theory is that it assumes that all participants have finite rationality.

Hypothesis 2: The Government's strategy space is: $A = \{A_1, A_2\}$ = {green taxes, non-green taxes},The probability of adopting

Figure 1
Strategy and mechanism of game subjects under green taxation



A_1 strategy is $x(0 \leqq x \leqq 1)$ The probability of adopting A_1 strategy is $1 - x$; the strategy space of local enterprises is $B = \{B1, B2\}$ = {new energy industry, non-new energy industry}, the probability of adopting B_1 strategy is $y(0 \leqq y \leqq 1)$, the probability of adopting B_2 strategy is $1 - y$; the strategy space of foreign enterprises is $C = \{C_1, C_2\}$ = {new energy industry, non-new energy industry, the probability of taking C_1 strategy is $Z(0 \leqq Z \leqq 1)$, the probability of taking C_2 strategy is $1 - Z$.

Hypothesis 3: The green tax policy implemented by the government will generate additional tax revenues ω; whereas a general tax at the standard rate will not generate additional net benefits. The implementation of a green tax policy will involve certain service costs including, but not limited to, staff training, financial product research and development, and other additional expenditure.

3.2. Modeling and solving

Based on the above assumptions, we can analogously obtain the payoff matrix of the tripartite group game of "government-local enterprises-foreign enterprises" on the transformation of new energy industry, which is shown in Table 1. The corresponding variable names are explained in Table 2.

Based on the game payoff matrix, the expected payoff of local firms adopting the "new energy" strategy is $U_1 1$, the expected payoff of local firms adopting the "non-new energy" strategy is U_{12}, and the average payoff of local firms is $\overline{U}_1$, that is:

$$\begin{aligned} U_{11} = {} & zx[(1-\lambda)(R_1+E_1)-(1-\beta)(1+i_g)I_1+\alpha] \\ & + z(1-x)[(1-\lambda)(R_1+E_1)-(1+i_g)I_1+\alpha] \\ & + (1-z)x[(1-\lambda)(R_1+E_1)-(1-\beta)(1+i_g)I_1+\alpha] \\ & + (1-z)(1-x)[(1-\lambda)(R_1+E_1)-(1+i_g)I_1+\alpha] \end{aligned} \tag{1}$$

$$\begin{aligned} U_{12} = {} & zx(R_1-\alpha)+z(1-x)(R_1-\alpha)+(1-z)x(R_1-\alpha) \\ & + (1-z)(1-x)(R_1-\alpha) \end{aligned} \tag{2}$$

$$\overline{U}_1 = yU_{11} + (1-y)U_{12} \tag{3}$$

The expected returns for a foreign company adopting a "new energy" strategy are U_{21}, the expected return of a "non-new energy" strategy is U_{22}, and the average return of the foreign firms is $\overline{U}_2$:

Table 1
Benefits matrix of the "government-local firms-foreign firms" game

Strategy selection		Local enterprise	Government: Green tax: *x*	Government: Non-green tax: *(1–x)*
Foreign companies	New energy industry: *z*	New energy industry: *y*	*(1 + ig)(I1 + I2) + w,* *(1 – α)(R1 + E1) – (1 – β)(1 + ig) I1 + α,* *(1 – γ)(R1 + E2 + δE1) – (I2 + βI1)(1 + ig) + α*	*(1 + ig)(I1 + I2),* *(1 – γ)(R1 + E1) – (1 – in) I1 + α,* *(1 – γ)(R2 + E2) – (1 + in) I2*
		Non-new energy industry: *(1 – y)*	*(1 + ig)I2 + w,* *R1 – α,* *(1 – γ)(R2 + E2) – (1 + ig)I2 + α*	*(1 + in)I2* *R1 – α,* *(1 – γ)(R2 + E2) – (1 + in) I2 + α*
	Non-new energy industry: *1 – z*	New energy industry: *x*	*(1 + ig) I1 + w,* *(1 – γ)(R1 + E1) – (1 - β)(1+ig) I1 + α,* *R2 + (1 – γ)δE1 – β(1 + ig) I1 – α*	*(1 + i)I1,* *(1 – γ)(R1 + E1) – (1 + in) I1 + α,* *R2 – α*
		Non-new energy industry: *(1 – x)*	*w,* *R1– α,* *R2– α*	*0,* *R1 – α,* *R2 – α*

Table 2
Parameter description

Parameters	Clarification
i_g	Green tax rates
i_n	Traditional tax base rate
$I_j(j=1,2)$	Costs of transitioning to a new energy industry for local and foreign enterprises
$R_j(j=1,2)$	Firms' gains when local and foreign firms innovate with traditional technologies
$E_j(j=1,2)$	Additional revenue from carbon credits, etc., for local and foreign enterprises transforming into new energy industries
ω	Governments develop additional tax revenues from green taxes
α	Indirect benefits such as environmental benefits from new energy industries for enterprises (or losses caused by non-new energy industries)
γ	Probability of risk of loss due to new energy ventures not meeting expectations $\lambda \in (0,1)$
β	Cost-sharing ratio $\beta \in (0,1)$
δ	Percentage of reimbursement received by field enterprises for cost-sharing $\delta \in (0,1)$

$$\begin{aligned} U_{21} = & \, yx[(1-\lambda)(R_2+E_2+\delta E_1)-(I_2-\lambda I_1)(1+i_g)+\alpha] \\ & +y(1-x)[(1-\lambda)(R_2+E_2)-(1+i_n)I_2+\alpha] \\ & +(1-y)x[(1-\lambda)(R_2+E_2)-(1+i_g)I_2+\alpha] \\ & +(1-y)(1-x)[(1-\lambda)(R_2+E_2)-(1+i_n)I_2+\alpha] \end{aligned} \tag{4}$$

$$\begin{aligned} U_{22} = & \, zx(R_1-\alpha)+z(1-x)(R_1-\alpha)+(1-z)x(R_1-\alpha) \\ & +(1-z)(1-x)(R_1-\alpha) \end{aligned} \tag{5}$$

$$\overline{U}_2 = zU_{21}+(1-z)U_{22} \tag{6}$$

The replication dynamics equation for local firms is obtained from Equations (1)–(6) as:

$$\begin{aligned} F(y) = & \, dy/dt = y(U_{11}-\overline{U}_1) \\ = & \, y(1-y)\{xI_1[1+i_n-(1-\beta)(1+i_g)]+(1-\lambda)(R_1+E_1) \\ & -(1+i_n)I_1-R_2+2\alpha\} \end{aligned} \tag{7}$$

Let $F(y)=0$ to get $y=0$, $y=1$ and $y = y^* = x = \{[\lambda(R_1+E_1) - 2\alpha - E_1 + (1+i_n)/I_1]/[1+i_n-(1-\beta)(1+i_g)]I_1\}$. (i) When $y = y^* = \{[\lambda(R_1+E_1) - 2\alpha - E_1 + (1+i_n)/I_1]/[1+i_n-(1-\beta)(1+i_g)]I_1\}$, $F(y)=0$. At this time, the strategy of the local firm does not receive the influence of the evolution system, and at any time, the evolution system is in a stable state, and the stabilizing strategy is an arbitrary strategy. (ii) When $y > y^*$, $F'(y)/(y=0)>0$, $F'(y)/(y=1)<0$, then $y=1$ (local enterprises carry out the transformation of new energy industry) is the stable strategy. (iii) When $y<y^*$, $F'(y)/(y=0)<0$, $F'(y)/(y=1)>0$, then $y=0$ (local enterprises undergo new energy industry transformation) is a stable strategy.

Proposition 1: As local firms' emission reduction gains rise, they will increase their investment in technology R&D, which prompts them to favor the transition to new energy industries.

Proposition 2: The government's green tax policy has an inverse effect on the propensity of local firms to adopt green technology innovation. Specifically, the lower the tax rate, the stronger the willingness of enterprises to choose new energy industry; conversely, the higher the tax rate, the more enterprises tend to abandon green technology innovation. Therefore, we can put forward Hypothesis 1: Increasing the level of green tax will effectively promote the development of new energy industry.

Proposition 3: Risk ratios are usually different in different regions and are affected by factors such as the level of regional economic development and fixed asset investment. In regions with higher level of economic development and better investment environment, the risk ratio is usually lower. Accordingly, hypothesis 2 can be proposed: the role of green tax in promoting the development of new energy industry has regional differences, which helps to narrow the gap in the development of new energy industry in different regions.

4. Conceptual Definition and Measurement of Development Indices

4.1. New energy industry development index measurement

After clarifying the concept of new energy, this study defines the new energy industry as a series of clusters of enterprises engaged in the research, manufacture, and application of new energy. The new energy industry is characterized by technology intensity [18]. Analyzed from the perspective of the industry chain, it can be categorized into upstream enterprises related to new energy resources, midstream enterprises producing new energy equipment, and downstream enterprises related to new energy consumption and use. Therefore, when measuring the development index of new energy industry, we need to synthesize the upstream, midstream, and downstream parts of the industry chain to derive a comprehensive index. Here, this paper refers to the hierarchical analysis—fuzzy comprehensive evaluation of the new energy industry development index to set up two secondary indexes under the index, respectively, for the regional new energy enterprise development index and regional new energy resource endowment index. Thus, we can get the formula of regional new energy industry development index:

$$\text{New}_{ind} = R_{ind} + E_{ind} \tag{8}$$

$$R_{ind} = \sum\nolimits_j \left(Q_{ind} * \sum\nolimits_{i=1}^{i=n} Com_{i,j} / \sum\nolimits_{i=1}^{i=N} Com_{i,j}\right) \tag{9}$$

$$E_{ind} = \sum_j \frac{\beta(i,j) * Q_{ind}}{\sum_i^{Q_{ind}} \beta(i,j)} \tag{10}$$

New_{ind} denotes the regional new energy industry development index, Q_{ind} denotes the number of regions with new energy enterprises in the whole country here $Q_{ind} = 28$, $Com_{(i,j)}$ denotes

Table 3
New energy industry development index system and indicators

Level 1 indicators	Secondary indicators	Tertiary indicators	orientations
New Energy Industry Development Index	New Energy Enterprise Development Index	Operating income (in millions of dollars)	+
		Net profit ($ million)	+
		Total R&D expenses ($ million)	+
		Total assets ($ million)	+
		Gearing ratio (%)	+
	New energy resource endowment index	Hydropower generation (billion kWh)	+
		Wind power generation (billion kWh)	+
		Solar power generation (billion kWh)	+
		Nuclear power generation (billion kWh)	+

the *j*th data of the *i*th enterprise, *n* denotes the number of regional new energy enterprises, *N* denotes the number of new energy enterprises in the whole country, R_{ind} denotes the development index of the regional new energy enterprises, E_{ind} denotes the level of endowment of the regional new energy resources. α_j denotes the score of the *j*th energy generation in the region, $\beta_{(i,j)}$ denotes the data of the jth energy generation in the first region, Q_{ind} denotes the number of regions with new energy enterprises in the whole country, $Q_{ind} = 30$ is taken here, and Rind denotes the index of regional new energy resource endowment. Measurement indicators are shown in Table 3.

4.2. Measurement results and analysis

In this paper, according to the above method based on Excel software to measure, get the new energy industry development index of each provincial administrative region, the specific results of the calculation and regional rankings are as follows.

As can be seen from Table 4, the level of development of new energy industry in China's provinces and municipalities in general showed a year-on-year growth trend, in which Beijing, Guangdong, Jiangsu, and other developed regions of the new energy industry development level is higher, which may be its own new energy enterprises more, especially Beijing presents a dominant phenomenon, Sichuan Province ranked fourth is mainly relying on its rich hydropower resources have a strong endowment of resources advantage. In contrast, Hainan, Tianjin, Hubei, and other regions of the new energy industry development level is significantly lower, which may be its own new energy enterprises less industrial chain is relatively backward, while taking into account the proportion of high-polluting industries in these regions is relatively more.

5. Models, Variables, and Data

5.1. Model selection (Hausman test)

In conducting empirical analyses, it is necessary to choose an appropriate model, and this study conducts the Hausman test based on Baltagi [19] method to determine which is more reasonable to choose between the random effects model and the fixed effects model in this study. The Hausman test results in Table 5 show that the *p*-value is much less than 0.1, indicating that the model that meets the sub-panel data cannot meet the assumptions of the Hausman test (assuming that the panel data should be analyzed using random effects), and therefore, the long panel data should be analyzed using fixed effects.

5.2. Empirical model setting

In order to test the impact of green tax on the development of new energy industry, this paper establishes the following full logarithmic model:

$$\ln New_{i,t} = \beta \ln G_{i,t} + \lambda X_{i,t} + \delta_t + \varepsilon_{i,t} \tag{12}$$

where the subscripts *i* and *t* denote the region and time, the explanatory variables; $\ln New_{i,t}$ denotes the level of development of new energy industry, taking the natural logarithm; $\ln G_{i,t}$ denotes the natural logarithm of the green tax index which is the

Table 4
New energy industry development index and ranking of individual provinces and municipalities in China, 2016–2021

Time Area	2016	2017	2018	2019	2020	2021	Geometric mean	Ranking
Beijing	66.44	65.17	67.32	69.36	68.18	64.54	66.83	1
Guangdong	21.03	22.28	22.25	21.37	22.03	22.90	21.98	2
Jiangsu	12.89	13.68	13.91	13.54	12.38	13.44	13.31	3
Sichuan	13.02	13.13	13.29	13.03	13.01	13.70	13.20	4
Xinjiang	11.31	10.91	9.71	9.45	9.78	10.14	10.22	5
Guizhou	3.75	3.88	3.96	3.91	4.38	4.60	4.08	25
Jiangxi	3.35	4.13	4.32	3.86	3.84	4.81	4.05	26
Guangxi	2.64	2.72	3.08	3.15	3.43	3.34	3.06	27
Tianjin	2.35	2.49	2.75	3.10	3.03	4.24	2.99	28
Heilongjiang	1.24	1.32	1.48	1.58	1.52	1.34	1.41	29
Hainan	0.48	1.40	1.36	1.41	1.44	1.46	1.26	30

Note: For reasons of space, the table includes the top five and the bottom five provinces.

Table 5
Hausman test results

Variable name	ln*New*
ln*G*	1.174**
	(−2.17)
ln*Lab*	0.061*
	(−1.65)
ln*Gov*	0.115***
	(−3.24)
ln*Pop*	−0.250***
	(−4.79)
_cons	−4.186***
	(−4.32)
N	180
adj R2	0.379

Note: *t*-test values in parentheses,* $p < 0.1$,** $p < 0.05$,*** $p < 0.01$,*, **,*** denote 1%, 5% and 10% significance levels respectively. Same as below.

core explanatory variable of interest in this paper; $X_{i,t}$ is the control variable; δ_t is the time fixed effect used to control for unobservable factors such as demographic changes in some short-term regional changes over time, administrative policies, natural disasters, etc.,; β and γ are the parameters to be estimated in this model; and the last item $\varepsilon_{i,t}$ is the random error term of the model.

5.3. Data cointegration test

The sample data are first tested for stationarity and then for cointegration. For the non-stationary time series variables, cointegration test is also needed to verify whether these data maintain a long-lasting cointegration relationship. Considering the superiority of IPS, Fisher ADF, and Fisher PP detection methods, this paper adopts the above methods for stability detection of panel data, and the results are shown in Table 6.

Table 6
Stability test results for panel data

Variant	IPS detection	Fisher ADF detection	Fisher PP detection	0.01 level
ln*New*	0.213 6	0.156 4	0.000 2	non-stationary
ln*G*	0.486 1	0.453 8	0.783 4	non-stationary
ln*Lab*	0.000 0	0.374 9	0.543 2	non-stationary
ln*Gov*	0.357 2	0.104 5	0.117 5	non-stationary
ln*Pop*	0.067 5	0.384 2	0.384 1	non-stationary
D(ln*New*)	0.000 0	0.000 0	0.000 0	stationary
D(ln*G*)	0.000 0	0.000 0	0.000 0	stationary
D(ln*Lab*)	0.000 0	0.000 0	0.000 0	stationary
D(ln*Gov*)	0.000 0	0.000 0	0.000 0	stationary
D(ln*Pop*)	0.000 0	0.000 0	0.0000	stationary

In this paper, *K*-test and *P*-test methods are used to detect cointegration in panel data. The results of the cointegration test are shown in Table 7.

The stability test results of the panel data can be seen from Table 6, and the variables ln*New*, ln*G*, ln*Lab*, ln*Gov*, and ln*Pop* are non-stationary variables, while the values of the variables after the function difference are all stationary variables. Therefore, we can continue to test the data for cointegration. From the data in Table 7, the *P*-value in *K*-test is less than 0.05 level which can reject the original hypothesis. In *P*-test, only two statistic values are higher than 0.05, and the rest of the statistics are lower than 0.05, which also rejects the original hypothesis. Therefore, the panel data maintains a cointegration relationship with each other.

5.4. Empirical model setting

The main explanatory variable of this study is green tax, in order to avoid ignoring variable errors, according to the existing research results, the article chooses the following variables as control variables: ① Human capital input (lnLab), the average wage of urban unit employed persons (yuan), taking the natural logarithm; ② Level of government expenditure (lnGov), the share of government expenditure in regional GDP, taking the natural logarithm; ③ Population size (lnPop), the number of permanent residents at the end of the year (10,000 people), taking the natural logarithm. The data for the control variables are mainly from the China Statistical Yearbook and the Statistical Yearbook of each provincial administrative region. The descriptive statistics of the main variables of this paper are shown in Table 8.

6. Empirical Results and Analysis

6.1. Correlation analysis and multiple covariance test

Since there may be interacting interaction between the explanatory variables resulting in the problem of multicollinearity, which will affect the explanatory strength of the model hence the need to test the correlation between the variables. Table 9 presents the pairwise correlations between the variables as well as the variance inflation factor (VIF). lnG is significantly and positively correlated with lnNew respectively, which initially confirms the proposed hypothesis. At the same time, the model does not suffer from serious multicollinearity problems because the VIF values are all less than the critical value of 10.

Table 7
Cointegration test results for panel data

Detection methods	Test hypothesis	Statistic	*P*-value	Test results
K Detection	H_0: ρ = 1	ADF	−6.854 73(0.000 0)	pass
P Detection	H_0: ρ = 1	Panel v-Statistic	−0.158 38(0.046 5)	pass
	H1: (ρ_1 = ρ)<1	Panel rho-Statistic	2.883 74(0.995 7)	fail to pass
		Panel PP-Statistic	−6.384 75(0.000 0)	pass
		Panel ADF-Statistic	−9.375 83(0.000 0)	pass
	H_0: ρ = 1	Group rho-Statistic	4.838 53(1.000 0)	fail to pass
	H_1: (ρ_1 = ρ)<1	Group PP-Statistic	−11.848 93(0.000 0)	pass
		Group ADF-Statistic	−11.183 53(0.000 0)	pass

Table 8
Variable definitions and descriptive statistics

Variable name	Sample size	Average value	Standard deviation.	Minimum value	Maximum values
ln*New*	180	1.846	0.749	−0.744	4.239
ln*G*	180	−1.177	0.180	−1.628	−0.723
ln*Lab*	180	11.30	0.252	10.81	12.18
ln*Gov*	180	3.191	0.377	2.367	4.212
ln*Pop*	180	8.217	0.743	6.366	9.448

Table 9
Correlation analysis and multiple covariance test

Variant	lnNew	ln*G*	ln*Lab*	ln*Gov*	ln*Pop*
ln*New*	1				
ln*G*	1.284***	1			
ln*Lab*	0.121***	0.053***	1		
ln*Gov*	0.034**	−0.017	0.390***	1	
ln*Pop*	0.007	−0.107***	0.241***	0.697***	1
vif	—	—	1.67	1.57	1.34

6.2. Benchmark regression analysis

Table 10 reports the results of the baseline regression and the unconditional quantile regression. Column (1) adds control variables as well as fixed time, and the results show that green taxes significantly increase the development of the new energy economy industry, and every 1 percentage point increase in its index can bring about a 1.6710% increase in the development index of the new energy industry, which verifies that Hypothesis 1 holds.

In order to clarify whether provinces at different stages of new energy industry development differ in the promotion of new energy industry development by green taxes, and whether green taxes lead to a widening or narrowing of the inter-county income gap, this study adopts an unconditional quantile regression (UQR) based on the impact function of the re-centering effect, and the marginal effect of green taxes on the development of new energy industry at each quantile position is Estimation. After analyzing the diversity of the parameters in depth, this study chose the five quartile positions of 10%, 30%, 50%, 70%, and 90% because they are more representative. Based on the results shown in columns (2), (3), (4), (5), and (6) in Table 10, it can be observed that green tax has a significant positive impact on the new energy industry index at different quartiles. Especially in the comparison between the high and low quartiles, the coefficient of the high quartile is relatively small. This suggests that green tax has a greater promotional effect on the provinces where the new energy industry is less developed. At the same time, it also indirectly indicates that green taxes help to reduce the differences in the development level of new energy industry between different regions while enhancing the overall level of regional new energy industry.

6.3. Heterogeneity analysis

After dividing the sample according to the three regions of East, Central, and West and estimating them separately, the results of the study are consolidated in Table 11. These results indicate that green taxes generally have a positive impact on the development of the new energy industry. However, specific to each region, the impact is not significant in the eastern region nor in the central region, while the impact in the western region is significant. This may mean that the effect of green tax in promoting the development of new energy industry varies from region to region, and it is not difficult to analyze the reason that there are more new energy enterprises in the eastern and central regions, and the industrial chain has already matured, so the development level of new energy industry is already at a high level and the overall construction and implementation of the tax mechanism is relatively complete, and the effectiveness of green tax incentives for promoting the development of new energy industry will be relatively low. At this time, the effectiveness of promoting the development of new energy industry through green tax incentive mechanism will be relatively low [20]. Therefore, the positive effect of green tax on the development of new energy industry is mainly manifested in the western region, which is economically underdeveloped but with high endowment of new energy resources, and the utilization of this effect can gradually narrow the gap between the development of new energy industry in the eastern and western regions, and also narrow the gap between the development of new energy industry in the eastern, central and western regions through the new industry catching up, which confirms that Hypothesis 2 of this paper is also valid.

Table 10
Benchmark regression results

Variable name	(1) Baseline regression	(2) q10	(3) q30	(4) q50	(5) q70	(6) q90
ln*G*	1.671 0 *** (5.051 8)	2.744 3 *** (3.138 1)	1.812 9 *** (6.718 6)	1.566 9 *** (5.651 2)	1.256 0 *** (3.735 6)	1.064 5 *** (3.842 2)
$X_{i,t}$	control	control	control	control	control	control
time fixed effects	control	control	control	control	control	control
N	180	180	180	180	180	180
adj. R 2	0.457	–	–	–	–	–

Table 11
Subregional regression results

Variant	(1) Eastern	(2) Central	(3) Western
ln*G*	1.816 1***	1.844 6***	1.751 0***
	(4.224 1)	(4.995 1)	(6.865 3)
ln*Lab*	3.092 9***	3.045 4***	4.215 2***
	(8.950 0)	(10.209 8)	(11.215 4)
ln*Gov*	0.052 2	0.067 9	0.067 7
	(0.203 1)	(0.310 6)	(0.426 5)
ln*Pop*	0.592 2***	0.608 5***	0.558 0***
	(4.807 1)	(5.943 1)	(7.286 6)
_cons	−35.706 5***	−35.783 1***	−48.401 3***
	(−7.753 8)	(−8.899 7)	(−10.736 1)
N	120	150	156
adj. R2	0.457	0.472	0.572

7. Conclusions and Policy Implications

Based on microdata from 199 new energy companies in the Wind database, along with energy and tax data from Chinese provinces, this paper measures the development index of the new energy industry and the level of green tax using a score accounting method and the entropy weighting method. It empirically analyzes the impact of green tax on the industry's development. The study finds that green tax significantly promotes the development of the regional new energy industry, and this conclusion remains robust even when accounting for endogeneity. Interestingly, the positive effect of green tax is not significant in the relatively high industrial development regions of the East and Central areas. However, in the western regions endowed with resources such as hydropower, wind power, and solar energy, green tax plays a significant role in promoting the new energy industry's development. In other words, green tax not only encourages the growth of the new energy industry but also gradually narrows the development gap between provinces.

The research in this paper not only provides empirical support for assessing the industrial impact of green taxes at the macro-level but also offers the following policy implications:

1) First, optimize the design of green tax policies. Considering the heterogeneity in the development of new energy industries across different regions, the government should implement region-specific green tax policies to more effectively promote green industry growth. Tools such as green tax exemptions, tax rate adjustments, and tax rebates should be tailored to the industrial structure, resource endowments, and development stages of various regions. For instance, in areas where the new energy industry is less developed, the government could increase tax incentives, offer more relief or subsidies, and encourage investment in new energy projects and technological research. In contrast, in regions where the industry is more mature, tax policies could be adjusted to encourage industrial upgrading and innovation for higher-quality green development.
2) Second, promote the synergy between green tax policy and regional economic development. The government should focus on boosting regional economic growth and fixed asset investment to strengthen the region's industrial base and create favorable conditions for implementing green tax policies. Specific measures include increasing investment in new energy infrastructure, improving public services and support facilities, establishing a dedicated fund to guide social capital into the new energy industry chain, and encouraging local governments to introduce preferential investment policies to attract green enterprises. Enhancing support for infrastructure, technological R&D, and talent acquisition can improve regional economic competitiveness, making green tax policies more effective.
3) Third, build a comprehensive green development policy system. The government should integrate green tax policy, industrial development level, resource endowment, and other dimensions to establish a holistic green development policy system that promotes both the new energy industry and the regional economy's green transformation. This could involve formulating green financial policies to support the financing and growth of green industries, establishing incentive mechanisms for resource management and environmental protection to ensure efficient resource use and pollution control, and enhancing regulations and policy packages to create a full-chain support system. By building a robust policy framework, the government can better guide enterprises toward low-carbon transformation, achieving a win-win scenario for economic and environmental benefits.

8. Limitations and Future Research

This study primarily evaluates the macro-level impact of green taxes, leaving the micro-level mechanisms—such as how green taxes affect firms' internal decision-making, investment strategies, and R&D in the new energy sector—relatively unexplored. Further studies could delve into these microeconomic aspects to clarify how green taxes translate into concrete changes within firms. Additionally, the study's focus on green tax does not consider the possible interactions with other complementary policies like subsidies, green financing, and renewable energy standards. Analyzing these combined policy effects could provide a more comprehensive understanding of the policy environment's influence on the new energy sector. Lastly, as green tax policies are subject to dynamic changes, their impact might vary with adjustments in tax rates, policy implementation methods, and evolving economic conditions. This study does not address how modifications in green tax design may alter its effectiveness. Future research could employ a dynamic approach to examine how changes in green tax policies impact the development of the new energy industry over time.

By addressing these limitations, future studies can present a more nuanced analysis of how green tax policies foster the growth of the new energy sector. This, in turn, would help inform more effective policy designs that promote sustainable and regionally balanced economic transitions.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

The data used in this study are all publicly available and can also all be found within this database: https://www.wind.com.cn/portal/zh/EDB/index.html.

Author Contribution Statement

Baoshuai Yao: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Changlin Li:** Software, Formal analysis, Writing – review & editing. **Rui Huang:** Validation, Investigation, Resources.

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