INVESTIGATING SPATIAL-TEMPORAL PATTERN AND INDUCING FACTORS TO GREEN TECHNOLOGY INNOVATION AND HIGH-QUALITY ECONOMIC DEVELOPMENT

Chen Yang [a], Xu Shaorui [b], Ali Farhan [c]

Abstract

Green development prioritizes ecology and sustainability and strengthens scientific and technological innovation to drive high-quality economic development. This paper constructs a coupled coordination model of a system evaluation index to explore the spatial and temporal pattern of green technology innovation and high-quality economic development. it also employs a Tobit regression model to analyse the influencing factors of coordinated development further. For this purpose, panel data on 30 Chinese provincial administrative regions were selected, ranging from 2010 to 2019. The results indicate that the level of coupling and coordination of green technology innovation with high-quality economic quality shows a steady upward trend and the evolution trend of "basic, moderate, and high coordination". At the same time, differences in coordinated development between regions are obvious, showing a development trend of "high in the east and low in the west". It is affected positively by the industrial structure, urbanization level, economic development level, R&D investment, foreign investment and education investment. In contrast, energy consumption has inhibited the coordinated development of green technology innovation and a high-quality economy coupling.

Keywords: Green technology innovation, high-quality economic development, coupling and coordination, Tobit model

JEL Classification: A14, C51, C52, O10, R10

a School of Economics, Fujian Normal University, Fuzhou, China
b Business college, Xiangtan University, Xiangtan, China
c Center for Economic Research, Shandong University, Jinan Shandong, China
Emails: cheny3598@gmail.com, xushaorui96@163.com, farhanalivirk@yahoo.com

1. Introduction

Faced with high resource and energy consumption and serious environmental pollution, which impedes good economic expansion, it is critical to accelerate a new green development model through high-tech content, lower resource usage and improved environmental quality.

China maintains its resolve and actions to pursue an ecologically prioritized, green and low-carbon development path, accelerate the green transformation, integrate carbon peaking and carbon impartiality into wide-ranging economic and public development planning, and release implementation plans for key areas and key industries in a step-by-step fashion. It aims to establish a “1+N” policy system, increase climate change efforts continuously, aim for carbon peak by 2030 and carbon neutrality by 2060, promote industrial transformation and upgrading with eco-friendly modernization, and achieve economic expansion and the dual benefits of addressing climate change.

With the advancement of the green development concept and the upgrading of the technology industry, experts and scholars have discovered that related research focuses primarily on technological innovation, green technology, ecological environment and industrial technology and primarily involves concept connotation definition, influence factors and measurement system construction. This article focuses on green technology, innovation, development and economic quality derivation.

Green technology novelty. In 1994, Braun and Wield first developed the idea of green technology. Domestic researchers have split the meaning of green technology innovation (GTI) into four categories: economic viewpoint, environmental perspective, process perspective and systematic perspective (Li and Yang, 2015). Industrial agglomeration and green technology innovation performance have been studied (Yang and Li, 2020; Ji *et al*., 2020), as well as environmental regulation (Guo, 2019; Chen and Li, 2020; Fan and Sun, 2020; Deng *et al*., 2021; Tao and Zhao, 2021). When reviewing China’s policies after the restructuring and opening up, it has been discovered that the nation’s green revolution has some issues, such as unclear rights and responsibilities, a low achievement transformation rate and weak legal constraints (Sun and Zhang, 2018). The green technology invention strategy emphasizes green technology, industry and green finance, intending to promote a “seamless link” between green technology innovation, industrial and capital chains (Zhuang *et al.*, 2020). To that end, the association coupling mechanism and level has been investigated (Li *et al.*, 2021).

First-class/superior/good economic development. The Communist Party of China’s (CPC) report to the 19th National Congress asks to establish a market-oriented system to encourage quality economic growth through green innovation, promote enterprise core competitiveness, industrial upgrading and the process of double-threshold effect (He and Wang, 2021), advanced industry and rationalization of some intermediary effects (Zhu and Gao, 2021). Simultaneously, investment and green technology progress negatively affect economic development (Wang and Wang, 2021).

Green technology and high-quality development research. With the rapid digital expansion, technology innovation has gradually become an important path of economic transformation and improving competitive strength. As the driving force of science and technology, innovation is vital in endorsing economic and social development (Wang *et al.*, 2021). Green technology innovation may conserve resources and minimize pollution by increasing production efficiency, energy conservation and emission reduction. It is an important part of achieving sustainable economic, social and ecological growth. Improved regional green technology innovation capability can help optimize the geographical pattern of development, resource allocation efficiency, industrial structure and economic growth quality and efficiency (Sun *et al.*, 2021). As a result, the influence of green technology innovation on economic evolution can help alleviate the scarcity of innovation resources, guide businesses to adopt a green development model, and promote the long-term sustainability of economy, population, resources and the environment; secondly, it can aid in the optimization of industrial development patterns, optimizing the industrial structure, alleviating energy crises and promoting high-quality development. Thirdly, it can serve as a model for others.

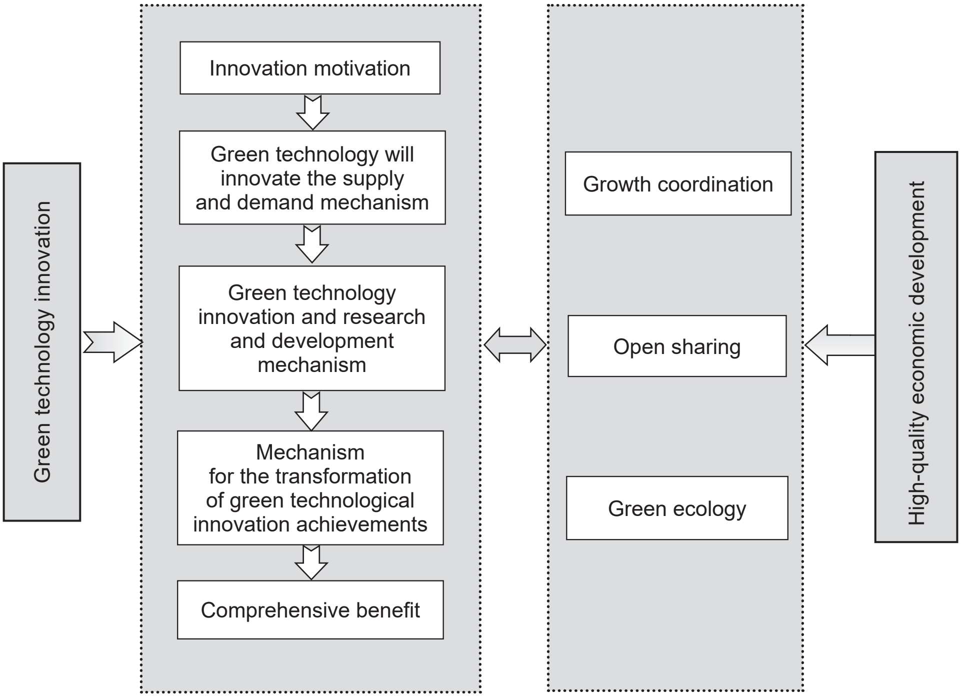
The paper's minor contribution explores the link between green technology innovation and environment-friendly economic development in reducing energy and resource tensions and attaining long-term economic growth. Future research should consider unique characteristics of different cities. Establishing a general rule or more accurate curve to explain the coupling relationship between them in various cities and counties can help understand the gap between local regions and provide a favourable guarantee for common prosperity.

2. Relationship Between GTI and HQED

Smith suggested in 1766 that there is an essential link between scientific and technological advancement and economic growth and that scientific and technological progress is a key ingredient in the process of continuing economic expansion. A city's economy must be self-sufficient in innovation to achieve high-quality development. Through technological innovation, the entire production factor quality can be improved, labour productivity and resource utilization can be improved, and the economic growth model for intensive, regional industrial structure with a knowledge-intensive and technology-intensive conversion can be promoted. Simultaneously, high-quality economic development (HQED) will give high-quality circumstances, a solid development platform and useful knowledge for company innovation. As a result, green technology innovation is a good means of inspiring good regional economic growth, and high-quality economic development is essential for technical innovation.

To begin with, green technology refers to a system that can cut consumption and pollution and improve ecology. Innovation refers to technological and management innovation aimed at environmental protection, which is a type of technological innovation. Green technology innovation will surely result in increased labour efficiency, energy conservation, emission reduction, resource conservation, pollution reduction and promotion of infrastructure and information services. It will undoubtedly lead to a high-quality economy characterized by coordinated economic development, innovation and openness, universal sharing and a green and sustainable economy.

Figure 1: Mechanism diagram of GTI driving HQED



Source: Authors

Secondly, green technology innovation should ensure quality and efficient growth of the economy by optimizing the geographical pattern of development, improving resource allocation efficiency, improving the manufacturing structure and efficient resource allocation. Only by achieving a high degree of coupling and harmonizing the two aspects of green technology innovation and high-quality economic growth can the current energy and resource crisis be alleviated. We will support green development and construct a market-concerned GTI system to create a robust economic outline for low-carbon and circular growth. Green technology is a type of technology that conserves natural resources, eliminates pollution and promotes long-term growth. Green technology innovation will become a vital support for ecological advancement, pollution prevention and control, and high-quality development as it continues to promote green development. Promoting green technology innovation, following a sustainable development path, raising environmental consciousness and supporting high-quality economic development are all unavoidable choices for promoting the economic development mode shift. We break through conventional technical innovation, apply green innovation and shift the traditional economic development model, the primary driver of high-quality economic development.

The preceding explanation demonstrates that green technology innovation (GTI) and HQED are objectively linked. They interact and influence each other through their respective coupling aspects, called green technology innovation and efficient economic growth coupling.

3. Evaluation of Degree of Coupling and Coordination of GTI and HQED

The coupled coordination model assesses how objects develop in a coordinated manner. The coupling degree is the impact of connection amid two or more systems on the dynamic correlation of coordinated development, indicating the degree of mutual limitation between systems. The extent of the benign coupling degree, also called coordination, might indicate a synchronization condition. Consider the association between national economic development and social well-being, the interaction between urbanization and the environment, scientific instigation and industrial structure, or the relationship between quality and quantity in sustainable development.

3.1 Construction of coupling structure index

Good-quality development aims to encounter people's increasing needs for a healthier life. Innovation drive has become a booster and speeds up the implementation of innovation-driven strategy, primarily for growth coordination, open sharing, green ecology, *etc.*

The index system is a critical foundation for a thorough evaluation. It should be used under scientific, practical, systematic and data availability standards because there is a multi-dimensional, complicated, coordinated link between GI and good economic development.

When constructing indicators, the green technology innovation index is separated into input and output, based on many studies (Zitong, 2015; Xiao, 2017; Wang, 2016; Tao, 2018). The share of green technology researchers in all employees, the number of businesses investing in green technology innovation, the proportion of green scientific research funds in sales volume, green expertise conversion and new product development funds, industrial pollution investment and management investment are all included in the green technology investment index. The revenue and the number of new product development projects, green copyrights for effective invention, the total profit of high-tech industries, the discharge of industrial wastewater per 10,000 yuan of GDP, the solid waste discharge per 10,000 yuan of GDP and the comprehensive utilization of industrial solid waste are all output indicators of green technology innovation.

The HQED index construction draws on the relevant research of Reading *et al*. (2015) and Lu *et al*. (2019). This paper sets the secondary indicators of HQED at three levels: growth coordination, openness and sharing and green ecology first. The three-level indicators for growth coordination are set as four three-level indicators: per capita GDP, proportion of consumer goods retail sales in GDP, industrial high polarization coefficient, and financial self-sufficiency coefficient. Per capita GDP is an important indicator of the level of economic development. Total retail sales of consumer goods reflect overall consumption in China. Consumption is one of the "triad" driving economic growth. The coefficient of industrial advancement and the financial self-sufficiency coefficient are alternative variables for the degree of coordination of China's industrial structure and government finance, respectively. Secondly, concerning the open sharing level, three indicators are set for the import and export of goods in proportion to GDP, per capita disposable income, unemployment, per capita education spending, per capita medical institution beds, per capita public library holdings, public transport vehicles per ten thousand people, per capita broadband Internet access, people's health, employment, education, health care, culture, transportation, and infrastructure for open sharing. Thirdly, the three-level indicators of green and ecological level are green coverage rate, per capita park green space area and rate of harmless treatment of household garbage. These three indicators can better reflect the relevant content of green development and ecological protection in China.

3.2 Data standardization

Because the original data units are not the same, it is impossible to compare and compute directly; thus, standardization is required:

Forward indicators:

$$Y_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}} \tag{1}$$

Reverse indicators:

$$Y_{ij} = \frac{x_{jmax} - x_{ij}}{x_{jmax} - x_{jmin}} \tag{2}$$

3.3 Calculation of index weights

The strong objective and operable entropy methods are employed to estimate the weight of each index of the two systems, respectively, to reduce the subjective consciousness of weight determination. The general procedures of the entropy method are as follows (Liao *et al*., 2018; Shi and Yang, 2020).

We calculate the percentages of each index, and then:

$$Y_{ij} = \frac{Z_{ij}^{'}}{\sum Z_{ij}^{'}} \tag{3}$$

Y_{ij} is the proportion of teh item j in the year I

We calculate the index of information entropy:

$$e_j = -k\sum_{i=1}^{m}\left(Y_{ij} \times Y_{ij}\right) \tag{4}$$

e_j is the entropy of the item j

We calculate the information entropy idleness:

$$d_j = 1 - e_j \tag{5}$$

d_j is the difference coefficient of the item j index

We calculate the index weight of the item j:

$$w_j = \frac{d_j}{\sum_{i=1}^{m} d_j} \tag{6}$$

w_j is the weight of the item j index.

3.4 Coupling and matching degree function

Rendering to the n-dimensional interaction coupling degree model:

$$C_n = n\left(\frac{U_1U_2\cdots U_n}{\prod(U_i+U_j)}\right)^{\frac{1}{n}} \tag{7}$$

C_n is the system coupling degree value, U_n represents the comprehensive evaluation index score.

The dual coupling function between GTI and HQED is obtained as shown below:

$$C_2 = 2\left(\frac{U_1U_2}{(U_1+U_2)(U_2+U_1)}\right)^{\frac{1}{2}} \tag{8}$$

C is the coupling degree of GTI and HQED, U_1 is the comprehensive score of GTI, U_2 symbolises the total score of HQED.

When C tends to 0, the coupling system is in an ineffective coupling state, indicating that GTI fails to sponsor HQED well. When C tends to 1, the coupling system is in an effective coupling state, representing the same.

Although the established coupling degree function can effectively calculate the coupling system composed of green technology innovation and high-quality economic development, it does not better reflect the real economic state and cannot reflect the actual economic significance between U_1 and U_2 due to a lack of data.

We also need to create a coupling matching degree function as follows:

$$\begin{cases} D = (CT)^K \\ T = aU_1 + bU_2 \end{cases} \tag{9}$$

D signifies the coupling matching gradation; C is the coupling mark between green technology innovation and high-quality economic progress; T shows the matching and reconciliation index, indicative of the matching effect; K, a, b is the pending coefficient, $K = 0.5$, $a = 0.6$, $b = 0.4$. The coupling system is classified into three categories according to the coupling matching degree, specifically expressed in the following manner:

Table 1: Classification system and discriminative standards for green technology innovation (GTI) and high-quality economic development (HQED)

No.	Coupling coordination degree (D)	Coupling coordination level
1	0.0 < D ≤ 0.2	Low coupling coordination
2	0.2 < D ≤ 0.4	Lower coupling coordination
3	0.4 < D ≤ 0.6	Moderate coupling coordination
4	0.6 < D ≤ 0.8	Higher coupling coordination
5	0.8 < D ≤ 1.0	Highly coupled coordination

Source: Authors

4. Empirical Analysis

The weight of each index is calculated according to Equations 1–6 and using Stata15 software. The specific system constructed is presented in Table 2.

Table 2: Index system of GTI and HQED

1st level	2nd level	3rd level	Unit	Sign	Weight
Green technology innovation *U1*	Investing in green technology innovation *X*1	Proportion of green technology researchers in total number of employees *X11*	%	+	0.07
		Number of enterprises investing in green technology innovation *X12*	–	+	0.09
		Green scientific research funds accounted for sales ratio *X13*	ten thousand yuan	+	0.07
		Green technology transformation funds *X14*	ten thousand yuan	+	0.06
		Green new product development funds *X15*	ten thousand yuan	+	0.08
		Industrial pollution investment and management investment *X16*	ten thousand yuan	–	0.05
	Green technology innovation output *X*2	Green new product sales revenue *X21*	ten thousand yuan	+	0.07
		Green new product development projects *X22*	piece	+	0.07
		Total profit of high-tech industry *X23*	ten thousand yuan	+	0.07
		Number of green patent applications *X24*	piece	+	0.07
		Number of effective invention green patents *X25*	piece	+	0.07
		Amount of industrial wastewater discharge per 10,000 yuan of GDP *X26*	tonne	-	0.02
		Solid waste emissions per 10,000 yuan of GDP *X27*	tonne	-	0.05
		Comprehensive utilization amount of industrial solid waste *X28*	%	+	0.03
High-quality economic development *U2*	Growth coordina-tion *Y*1	Per capita GDP *Y11*	yuan	+	0.08
		Industrial high polarization coefficient *Y12*	%	+	0.07
		Retail sales of consumer goods accounted for GDP *Y13*	%	+	0.04
		Fiscal self-sufficiency ability coefficient *Y14*	%	+	0.09
	Open sharing *Y*2	Total import and export volume accounted for *Y21*	%	+	0.08
		Per capita disposable income *Y22*	yuan	+	0.08
		Internet broadband interface per capita *Y23*		+	0.08
		Urban registered unemployment rate *Y24*	%	+	0.06
		Per capita education expenditure *Y25*	yuan	+	0.06
		Medical institution beds per capita *Y26*		+	0.04
		Public library holdings per capita *Y27*	volume	+	0.08
		Per 10,000 people *Y28*		+	0.07
	Green ecology *Y*3	Urban greening coverage rate *Y31*	%	+	0.07
		Per capita green park area *Y32*	centiare	+	0.04
		Harmless treatment rate of household waste *Y33*	%	+	0.06

Source: China Statistical Yearbook and China Environmental Statistics Yearbook, elaborated by authors

Table 3: Comprehensive index of GTI and HQED system in all Chinese provinces and cities

		U1			U2		
Region	**Province**	**2010**	**2019**	**Mean value**	**2010**	**2019**	**Mean value**
East	Beijing	0.47	0.58	0.53	0.74	0.87	0.81
	Tianjin	0.34	0.54	0.44	0.56	0.59	0.58
	Hebei	0.36	0.56	0.46	0.36	0.36	0.36
	Shanghai	0.58	0.57	0.58	0.82	0.86	0.84
	Jiangsu	0.65	0.80	0.73	0.66	0.67	0.67
	Zhejiang	0.49	0.68	0.59	0.59	0.7	0.65
	Fujian	0.42	0.59	0.51	0.5	0.58	0.54
	Shandong	0.24	0.61	0.43	0.47	0.59	0.53
	Guangdong	0.89	0.84	0.87	0.5	0.58	0.54
	Hainan	0.14	0.51	0.33	0.36	0.47	0.42
Central	Shanxi	0.20	0.56	0.38	0.34	0.4	0.37
	Anhui	0.37	0.59	0.48	0.32	0.44	0.38
	Jiangxi	0.16	0.58	0.37	0.33	0.42	0.38
	Henan	0.17	0.57	0.37	0.31	0.41	0.36
	Hubei	0.17	0.58	0.38	0.36	0.46	0.41
	Hunan	0.16	0.57	0.37	0.34	0.5	0.42
West	Nei Monggol	0.12	0.37	0.25	0.35	0.4	0.38
	Guangxi	0.13	0.37	0.25	0.33	0.4	0.37
	Chongqing	0.15	0.54	0.35	0.43	0.51	0.47
	Sichuan	0.22	0.59	0.41	0.37	0.48	0.43
	Guizhou	0.14	0.54	0.34	0.28	0.28	0.28
	Yunnan	0.12	0.54	0.33	0.34	0.43	0.39
	Xizang	0.11	0.34	0.23	0.32	0.37	0.35
	Shaanxi	0.17	0.56	0.37	0.39	0.46	0.43
	Gansu	0.12	0.52	0.32	0.19	0.34	0.27
	Qinghai	0.09	0.57	0.33	0.33	0.33	0.33
	Ningxia	0.09	0.33	0.21	0.4	0.48	0.44
	Xinjiang	0.12	0.42	0.27	0.43	0.37	0.40
North-east	Liaoning	0.46	0.55	0.51	0.42	0.51	0.47
	Jilin	0.24	0.53	0.39	0.31	0.43	0.37
	Heilongjiang	0.37	0.53	0.45	0.31	0.44	0.38
	Mean value	0.27	0.55	–	0.41	0.49	-

Source: China Statistical Yearbook and China Environmental Statistics Yearbook, elaborated by authors

The weight is calculated using the entropy method and the data after standardization are weighted using the linear weighting method to calculate the two systematic, comprehensive-level indices of GTI and HQED.

$$U_1(U_2) = \sum_{i=1}^{n} w_{ij} U_{ij} \tag{10}$$

U_1 and U_2 represent the comprehensive evaluation indices of GTI and HQED.

According to the standardized index values and their weights, each subsystem's comprehensive index is calculated using the above formula and the comprehensive index of GTI and HQED systems in each region. Due to the limited length of the article, the data results for 2010 and 2019 are listed here. The details are shown in Table 3.

The comprehensive index of each subsystem is generated using the above method based on the standardized index values and weights, and the coupling and coordination degree between green technology innovation and high-quality economic growth is determined using the formula. Table 4 summarizes the outcomes of the calculations.

From 2010 to 2019, China's GTI and HQED coupling increased, with a high coupling in 2019, near disorder in the central region, barely any coordination in the western region, and finally good coordination in the eastern region, indicating that China's GTI and HQED overall level is high, and GTI drives HQED. In the central and eastern regions, the coupling value between GTI and HQED exceeds 0.5, indicating basic coordination, intermediate coordination, between GTI is 0.5, indicating an imbalance between GTI and HQED. The results in Table 5 were obtained using data from 2010 to 2019 to calculate the degree of GTI and HQED system coordination in 31 provinces and cities in China and the coordination value of GTI in 10 years and HQED.

Table 4: Degree of coupling between China's GTI and HQED

Region	Province	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Mean value
East	Beijing	0.78	0.89	0.85	0.81	0.93	0.87	0.90	0.92	0.92	0.91	0.88
	Tianjin	0.52	0.59	0.58	0.62	0.82	0.71	0.64	0.62	0.58	0.74	0.64
	Hebei	0.45	0.44	0.41	0.45	0.60	0.59	0.55	0.53	0.50	0.59	0.51
	Shanghai	0.71	0.70	0.70	0.77	0.98	0.85	0.77	0.82	0.72	0.90	0.79
	Jiangsu	0.68	0.81	0.85	0.79	0.79	0.91	0.82	0.90	0.80	0.90	0.83
	Zhejiang	0.60	0.67	0.67	0.67	0.80	0.82	0.75	0.79	0.75	0.87	0.74
	Fujian	0.53	0.56	0.54	0.56	0.95	0.69	0.67	0.68	0.65	0.76	0.66
	Shandong	0.44	0.59	0.60	0.61	0.82	0.74	0.67	0.69	0.65	0.75	0.66
	Guangdong	0.70	0.85	0.92	0.85	0.90	0.98	0.92	0.98	0.99	0.96	0.91
	Hainan	0.34	0.43	0.42	0.45	0.45	0.58	0.53	0.50	0.52	0.65	0.49
Middle	Shanxi	0.37	0.41	0.37	0.41	0.46	0.56	0.50	0.46	0.46	0.62	0.46
	Anhui	0.44	0.44	0.44	0.43	0.62	0.59	0.53	0.54	0.53	0.66	0.52
	Jiangxi	0.34	0.43	0.43	0.41	0.56	0.58	0.52	0.54	0.52	0.65	0.50
	Henan	0.33	0.41	0.40	0.39	0.64	0.57	0.50	0.50	0.50	0.64	0.49
	Hubei	0.35	0.46	0.47	0.45	0.88	0.61	0.55	0.59	0.53	0.67	0.56
	Hunan	0.34	0.44	0.44	0.45	0.69	0.61	0.55	0.61	0.54	0.70	0.54
West	Guangxi	0.32	0.40	0.39	0.39	0.42	0.52	0.47	0.44	0.46	0.61	0.44
	Nei Monggol	0.38	0.47	0.46	0.50	0.59	0.65	0.58	0.57	0.56	0.70	0.55
	Chongqing	0.39	0.48	0.49	0.49	0.73	0.63	0.58	0.59	0.56	0.69	0.56
	Sichuan	0.30	0.37	0.37	0.33	0.50	0.53	0.48	0.45	0.46	0.52	0.43
	Guizhou	0.32	0.39	0.37	0.39	0.41	0.52	0.47	0.44	0.47	0.64	0.44
	Yunnan	0.37	0.29	0.46	0.47	0.76	0.62	0.57	0.54	0.52	0.67	0.53
	Xizang	0.24	0.16	0.31	0.33	0.32	0.43	0.38	0.40	0.43	0.57	0.38
	Shaanxi	0.28	0.21	0.33	0.33	0.31	0.49	0.45	0.41	0.43	0.58	0.43
	Gansu	0.32	0.24	0.38	0.39	0.40	0.56	0.45	0.49	0.51	0.57	0.43
	Qinghai	0.32	0.24	0.39	0.41	0.46	0.51	0.50	0.46	0.47	0.55	0.55
	Ningxia	0.38	0.47	0.46	0.50	0.59	0.65	0.58	0.57	0.56	0.70	0.56
	Xinjiang	0.39	0.48	0.49	0.49	0.73	0.63	0.58	0.59	0.56	0.69	0.44
North-east	Liaoning	0.52	0.53	0.50	0.50	0.67	0.65	0.60	0.59	0.58	0.70	0.58
	Jilin	0.37	0.42	0.41	0.44	0.46	0.56	0.51	0.45	0.50	0.63	0.48
	Heilongjiang	0.44	0.42	0.42	0.42	0.53	0.57	0.51	0.48	0.48	0.64	0.49

Source: China Statistical Yearbook and China Environmental Statistics Yearbook, elaborated by authors

Table 5: Degree of coupling between China's GTI and HQED

Region	Mean value	Rank	Coupling coordination values	Coordination level
Guangdong	0.91	1	0.9 < D ≤ 1	High-quality and coordinated development
Beijing	0.88	2	0.8 < D ≤ 0.9	Well-coordinated development
Jiangsu	0.83	3		
Shanghai	0.79	4	0.7 < D ≤ 0.8	Intermediate coordinated development
Zhejiang	0.74	5		
Fujian	0.66	6	0.6 < D ≤ 0.7	Basic coordinated development
Shandong	0.66	7		
Tianjin	0.64	8		
Liaoning	0.58	9	0.5 < D ≤ 0.6	Barely coordinated development
Hubei	0.56	10		
Ningxia	0.56	11		
Chongqing	0.56	12		
Nei Monggol	0.55	13		
Qinghai	0.55	14		
Hunan	0.54	15		
Yunnan	0.53	16		
Anhui	0.52	17		
Hebei	0.51	18		
Jiangxi	0.5	19	0.4 < D ≤ 0.5	Verge of non-regulation and recession
Hainan	0.49	20		
Henan	0.49	21		
Heilongjiang	0.49	22		
Jilin	0.48	23		
Shanxi	0.46	24		
Guangxi	0.44	25		
Guizhou	0.44	26		
Xinjiang	0.44	27		
Gansu	0.43	28		
Shaanxi	0.43	29		
Sichuan	0.43	30		

Source: China Statistical Yearbook and China Environmental Statistics Yearbook, elaborated by authors

The results of the coordination level of GTI and HQED in various provinces and cities in China show that the value of the coupling coordination degree in Guangdong Province, ranked first, was between 0.9 and 1, and the coordination level was high-quality coordinated development; the value of the coupling coordination degree in Beijing and Jiangsu Province, ranked second, was between 0.8 and 0.9, and the coordination level was good coordination. The coupling coordination degree between GTI and HQED in Tianjin and another three provinces and cities is between 0.7 and 0.8, and the coordination is in the intermediate stage of coordinated development; the coupling coordination degree between GTI and HQED in Liaoning, Hubei, Ningxia, Chongqing, Inner Mongolia, Qinghai, Hunan, Yunnan, Anhui and Hebei is between 0.6 and 0.7, and the coordination level is in the basic coordinated development stage. The coupling coordination between GTI and HQED in Sichuan and other provinces and cities (Jiangxi, Hainan, Henan, Heilongjiang, Jilin, Shanxi, Guangxi, Guizhou, Xinjiang, Gansu and Shaanxi) is between 0.5 and 0.6, and the coordination is in a state of barely coordinated development, and the comprehensive China 30 shows that the coupling coordination between GTI and HQED varies greatly between provinces.

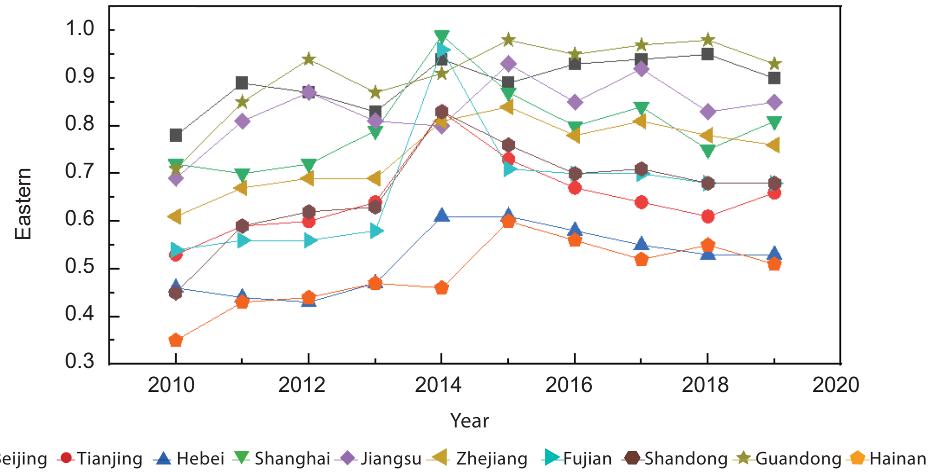
5. Analysis of Coordinated Heterogeneity of Coupling Between GTI and HQED

5.1 Time evolution analysis

Based on the statistics for 2010–2019 and the coupling degree model, we calculate the coupling of GTI and HQED relationship; according to the economic development level, China is divided into the eastern, central, western and northeast region. The time change level and the provincial level of the coupling degree are shown in the following figure.

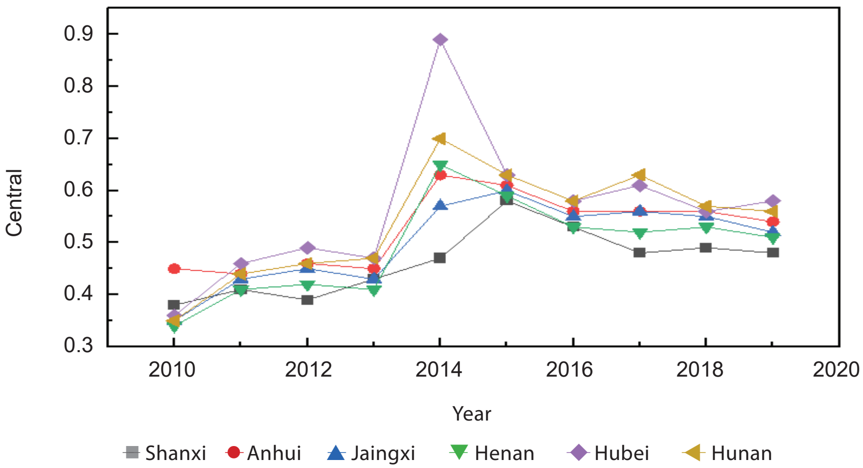
As shown in Figure 2, the degree of coupling between green technology innovation and high-quality economic growth in Eastern China grows year by year, with Hainan Province having the lowest coupling degree in 2010 and gradually improving year by year. Green technology innovation and high-quality economic growth had a higher coupling value in 2019 than in Hebei Province. Guangdong province scored top in the eastern regions regarding green technology innovation and high-quality economic development from 2010 to 2019 and was the highest in 2014.

Figure 2: Statistical chart of coupling degree of GTI and HQED in Eastern China



Source: Own analysis

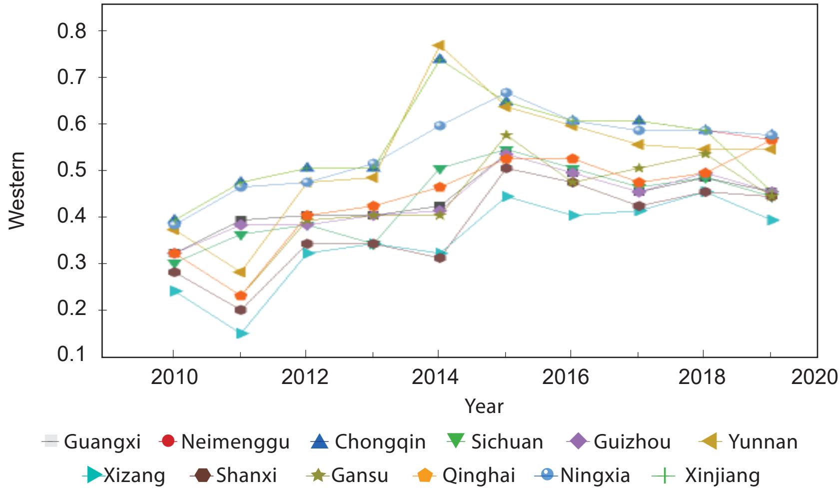
Figure 3: Statistical chart of coupling degree of GTI and HQED in Central China



Source: Own analysis

Figure 3 shows that in Central China, the degree of coupling between GTI and HQED is typically between 0.4 and 0.7. Hubei Province has strong GTI and HQED among the central provinces and cities, with a good breakthrough and leap index of 0.88 in 2010. From 2010 to 2019, the coupling index of Hunan, Jiangxi and Anhui provinces is very concentrated, with the majority in the barely coordinated development range of 0.5 to 0.6.

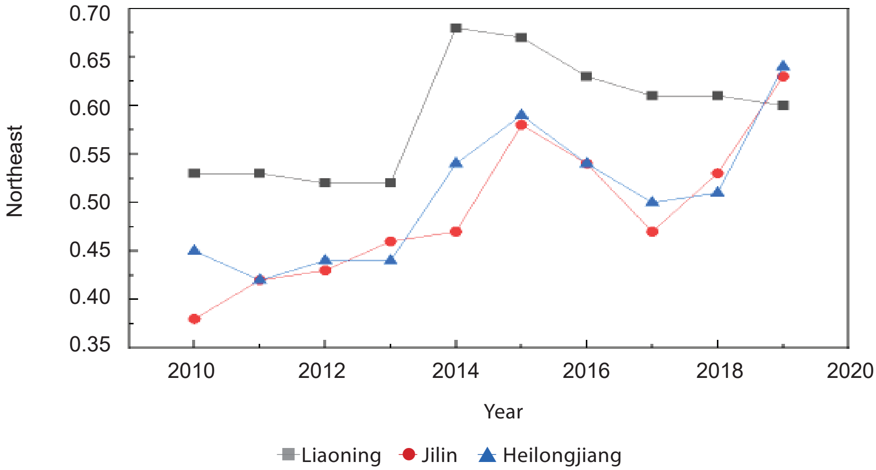
Figure 4: Statistical chart of coupling degree of GTI and HQED in Western China



Source: Own analysis

Figure 4 shows that the coupling index of GTI and HQED in all provinces in Western China was typically below 0.5 from 2010 to 2014 and that it was in force and losing coordination from 2014 to 2019. In 2019, each province's coupling degree index was largely concentrated, highlighting the years of investment in GTI to foster HQED.

Figure 5: Statistical chart of coupling degree of GTI and HQED in Northeast China



Source: Own analysis

In Figure 5, the coupling index of GTI and HQED in Northeast China ranged from 0.05 to 0.5 from 2014 to 2018, rapidly increasing after 2018, especially in Liaoning Province, which further demonstrates the continuous development of Northeast China's old industrial base and thus encourages high-quality economic development.

5.2 Analysis of spatial evolution

To further explore the spatial differences in green technology innovation and high-quality development, we used Arcgis10.8 software for 2010, 2014, 2016 and 2019 to identify four-time section green technology innovation and economic quality development coupling for 30 provinces' coordinated development as a spatial visual analysis (no interpretation due to data on Tibet, Hong Kong, Macao and Taiwan missing), expressed as follows.

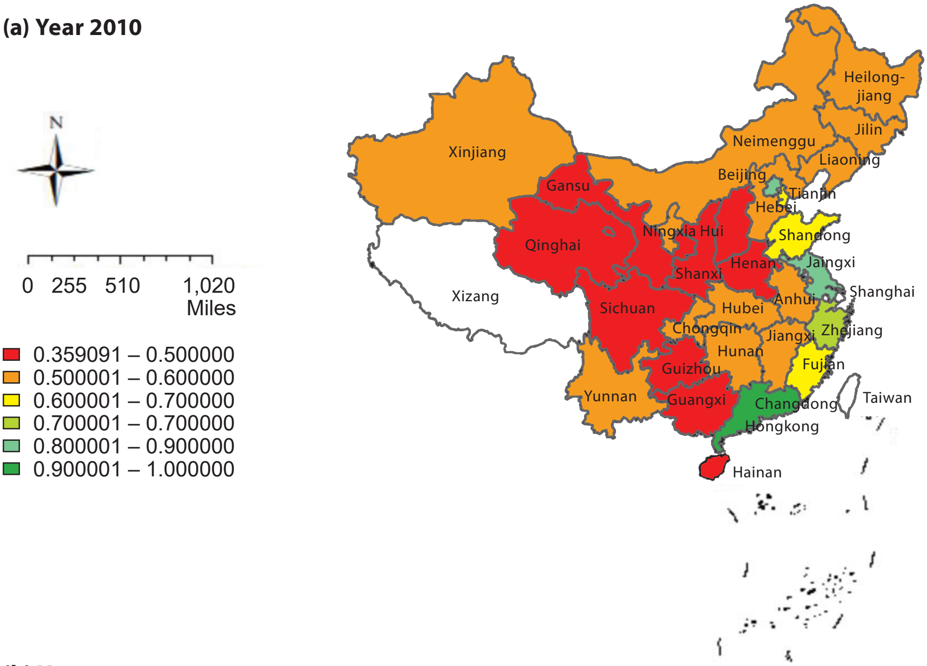
In the spatial diagram in Figure 6, green indicates a high degree of coupling, red indicates a low degree of coupling, and white is missing data. In 2010, the provincial and municipal areas with a high coupling coefficient of GTI and HQED are: Beijing, Guangdong Province, Jiangsu Province; the provinces and cities at the second level are: Fujian Province, Liaoning Province, Zhejiang Province; and the provinces and cities at the third level are: Hubei Province, Hunan Province, Jiangxi Province, Inner Mongolia, Xinjiang, *etc.* We found that the coupling coefficient in the eastern region is higher, while the coupling coefficient in the central and northeastern regions is at the second level, and the coupling coefficient in the western region is the lowest; it further shows that the central and eastern regions have developed rapidly at the economic level, there are more high-tech enterprises, and the investment in the scientific and technological level is higher, which is consistent with China's economic development.

In 2014, the coupling coefficient of GTI and HQED was at a high level in provinces and cities: Beijing, Guangdong Province, Jiangsu Province, Zhejiang Province, Fujian Province, Hubei Province, *etc.;* the provinces and cities at the second level are: Liaoning Province, Yunnan Province, Chongqing, *etc.* We found that in 2014, the coupling coefficient of GTI and HQED in various provinces and cities had increased, and the green science and technology investments in high-tech industries in the central region were rising, thereby enhancing the rapid growth of the central economy.

In 2016, the coupling coefficient between GTI and HQED was at a high level in provinces and cities: Beijing, Guangdong Province, Jiangsu Province, Shandong Province, *etc.*; the provinces and cities at the second level were: Fujian Province, Liaoning Province, Zhejiang Province, Hubei Province, Hunan Province, Jiangxi Province, *etc.*; the provinces and cities at the lowest development level were: Gansu, Qinghai, *etc.*, all in the western region.

Figure 6: Coupling degree coefficient of regional GTI and HQED in China

(a) Year 2010



(b) Year 2014

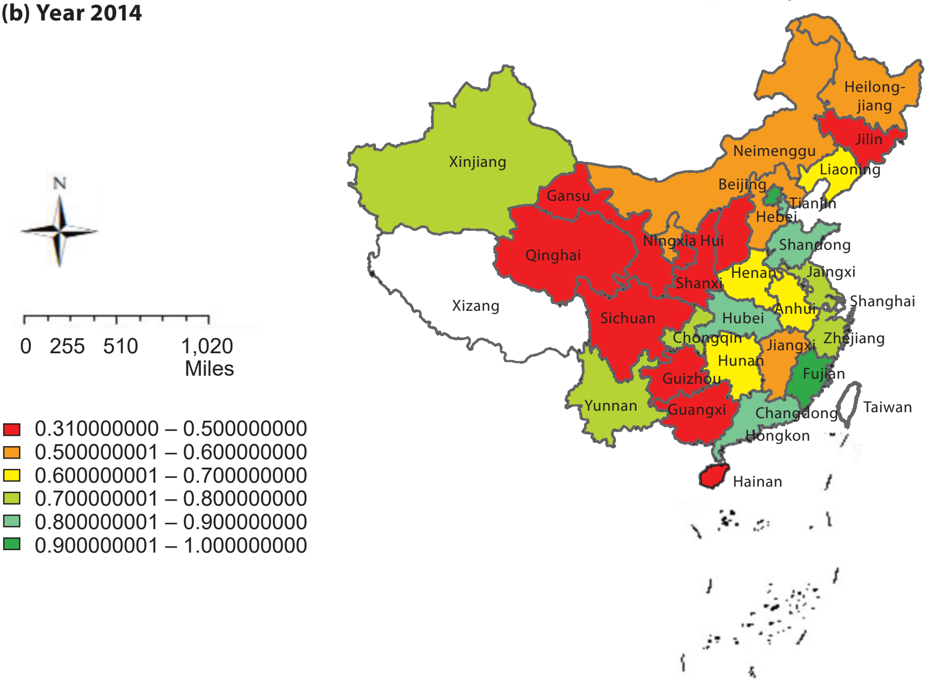
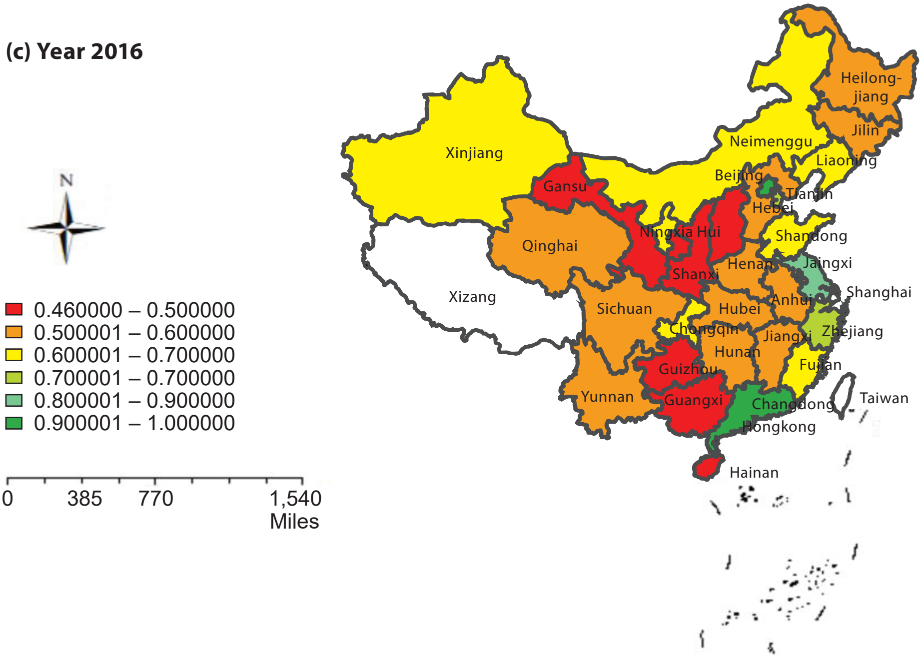
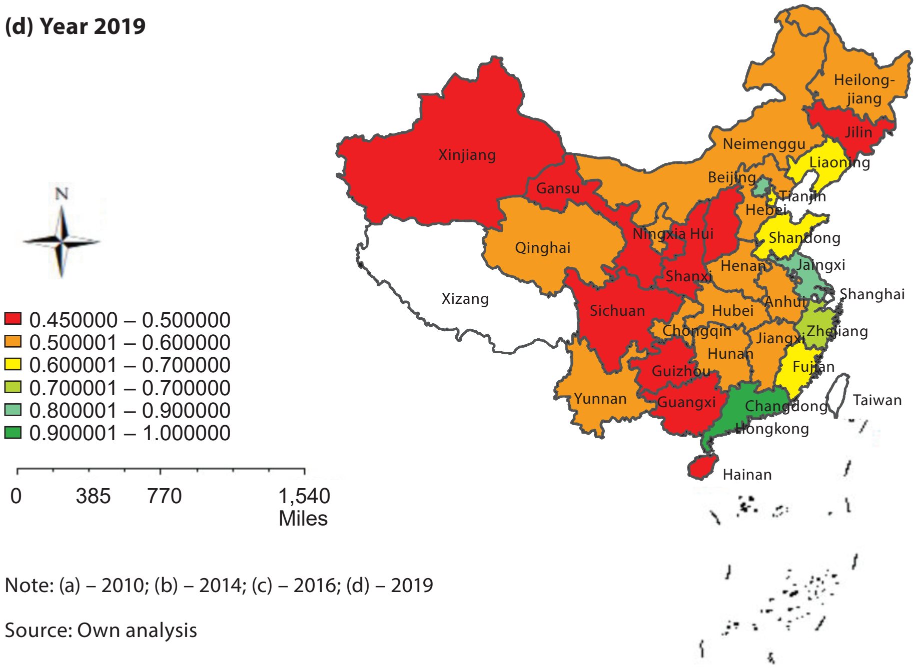


Figure 6 (Continuation)

(c) Year 2016



(d) Year 2019



Note: (a) – 2010; (b) – 2014; (c) – 2016; (d) – 2019

Source: Own analysis

In 2019, the coupling coefficient between GTI and HQED in all provinces and cities in China was higher than 0.5, but differences between provinces and regions were obvious. The investment in green science and technology in the eastern region is still at the first level, the central and northeastern regions are in the second place, and the development of the western region is in the last; the investment in technological innovation in Sichuan Province, Shaanxi Province, Guizhou Province and other provinces has increased, and the economy has made remarkable achievements.

6. Analysis of Dynamic Factors of GTI and HQED

The coupling and coordinated development of GTI and HQED are affected by a variety of factors concerning existing research, and are combined with the actual situation, from the industrial structure, urbanization level, economic development level, R&D investment, foreign investment, education investment, energy consumption intensity, *etc*., to construct an indicator system by constructing econometric models to carry out measurements. The construction indicators are shown in Table 6.

Table 6: Dynamic factors of degree of coupling and coordination

Variable	Name	Symbol	Measurement methods	Unit
Explained variable	Coupling coordination degree	*Dit*	Results of coupled coordination degree model calculation	
Explanatory variable	Industrial structure	*Ei*	Output value of tertiary industry accounts for GDP of prefecture-level cities	%
	Urbanization level	*Urb*	Urbanization rate	%
	Economic development level	*Eco*	Real GDP per capita	CNY
	Research input	*Rd*	R&D personnel full-time equivalent	Person
	Foreign investment	*FDI*	Amount of foreign direct investment	Dollar
	Investment in education	*Educ*	Proportion of education expenditure in GDP	%
	Energy consumption intensity	*Ene*	Ratio of total energy consumption to per capita GDP	Ten thousand tonnes of standard coal/CNY

Source: China's Statistical Yearbook and Environmental Statistics Yearbook

Before the empirical analysis using a Tobit model, a multicollinearity test was conducted for each variable, and the variance expansion factor (VIF) of the explanatory variables was between 1.45 and 7.36. The maximum value was less than 10, so multicollinearity interference was excluded.

Table 7: Multicollinearity test results

	Ei	*Urb*	*Eco*	*Rd*	*FDI*	*Educ*	*Ene*
VIF	2.94	7.36	7.16	3.80	2.36	1.45	2.14
1/VIF	0.3407	0.1358	0.1396	0.548	0.4233	0.6916	0.4675

Source: Authors' calculation using Stata15 software

The coupling coordination value changes between 0 and 1. The explained variable has the characteristics of being cut (truncated), which meets the setting conditions of the restricted dependent variable Tobit regression model. This paper uses the random-effect panel Tobit model for estimation. The random-effect panel Tobit model is consistently estimated relative to the fixed-effect panel Tobit model, which can effectively avoid the biased results caused by least-squares regression. The model is set as follows:

$$D_{it} = cons + \beta_1 Ei_{it} + \beta_2\, Urb_{it} + \beta_3 Eco_{it} + \beta_4 Rd_{it} + \beta_5\, FDI_{it} + \beta_6 Educ_{it} + \beta_7 Ene_{it} + \varepsilon_{it} \tag{11}$$

D_{it} is the degree of coupling coordination, i represents the region, t represents the time; *cons* is the constant term; *Ei* is the industrial structure; *Urb* is the level of urbanization; *Eco* is the level of economic development; *Rd* is the investment in research and development; *FDI* is the foreign investment; *Educ* is the investment in education; *Ene* is the intensity of energy consumption, and ε_{it} is the random perturbation term. Using Stata15 econometric analysis software, the Tobit regression of a random-effect panel is carried out, and the results are shown in Table 8.

From the perspective of the calculation structure at the national level, the regression coefficient of the industrial structure is 0.009, and it is significant at the level of 1%, indicating that the adjustment of the industrial structure is conducive to the coupling and coordinated development of GTI and HQED. The economic development level and the coupling coordination index have a significant positive correlation. The regression coefficient is 0.3210, and it is significant at the 1% level, indicating an improvement in the city's economic strength. The regression coefficient of R&D investment is positive. It is significant at 1%, indicating that increasing R&D investment and the consequent scientific and technological progress are an important driving force for the coupling and coordinated development of GTI and HQED. Accelerating scientific and technological innovation and high-tech industry development can effectively improve energy efficiency, reduce energy consumption and promote environmental pollution control capabilities and management efficiency. The regression coefficient of energy consumption intensity is negative. It is significant at the level of 10%, indicating that the utilization of energy resources hurts the coupling and coordinated development of GTI and HQED, mainly because in the face of the global energy crisis, resource and energy consumption is large, and high pollution, high energy consumption and high emissions in some areas have caused great damage to the environment while accelerating the transformation of the development mode, adjusting the industrial structure and accelerating the construction of a resource-saving and environment-friendly society. It has become an important part of the coupling and coordinated development of promoting green technology innovation and high-quality economic development.

Table 8: Regression results

	Nationwide		Eastern		Central		Westward		Northeast	
Variable	**Coef.**	**P**	**Coef.**	**P**	**Coef.**	**P**	**Coef.**	**P**	**Coef.**	**P**
Ei	0.009	0.002***	0.006	0.033**	−0.068	0.043**	0.010	0.002*	0.012	0.070*
Urb	0.005	0.007***	0.004	0.105	0.010	0.060*	0.008	0.004**	0.014	0.140
Eco	0.322	0.000***	0.020	0.370	0.530	0.035**	0.823	0.013**	0.031	0.003***
Rd	0.087	0.005***	0.008	0.007***	0.013	0.080*	0.005	0.143	0.057	0.043**
FDI	0.021	0.017**	0.002	0.037**	0.001	0.090*	0.026	0.012**	0.024	0.027**
Educ	0.008	0.000***	0.018	0.044**	0.211	0.018**	0.003	0.027**	0.383	0.064
Ene	−0.064	0.082*	−0.063	0.000*	0.003	0.120**	−0.021	0.120	−0.037	0.182
cons	−0.082	0.000***	0.038	0.000***	−0.287	0.090*	−0.197	0.020**	−0.584	0.000***

Note: *, **, and *** are significant at the 10%, 5%, and 1% levels.
Source: Authors' calculation using Stata15 software

From the perspective of the four regions, the return coefficient of foreign investment is positive. All of them pass the 5% test, indicating that each region urgently needs to expand its opening up to the outside world, attract large amounts of foreign funds, technologies and talents, drive industrial restructuring, transformation and upgrading, cultivate and strengthen emerging industries, and thus promote the coupling and coordinated development of GTI and HQED. The impact of the economic development level in the eastern region is not significant. In contrast, the central and western regions pass the 5% test, and the northeast passes the 1% test, which further shows that the economic development in the eastern region of China is relatively rapid. The environmental pollution is more serious, and other regions are aware of environmental pollution at the same time as the economic development to promote the coupling and coordinated development of GTI and HQED.

7. Conclusions

To promote economic quality development and close the regional gap for high-quality regional coordinated development into common prosperity, it is necessary to give full attention to GTI to promote HQED. Based on an in-depth study and related research results at home and abroad, using quantitative and qualitative coupling coordination research methods, the study has made the following findings.

Firstly, an analysis of green technology innovation and high-quality economic development in all Chinese provinces and cities from 2010 to 2019 revealed a tendency for rapid growth. The volatility of green technology innovation development levels has shifted from "tortuous changes" to "stable growth" to "fast growth".

Secondly, between 2010 and 2019, the coupling degree (C) and coordination degree development (D) values between GTI and HQED in all provinces and cities steadily increased yearly, indicating that the correlation and closeness between systems are increasing. In four time points, the coordinated growth of GTI and HQED in 31 provinces and cities revealed clear development differences. On the other hand, 2010, 2014, 2016 and 2019 are the years in which the numerical variations in the degree of coordinated development in the western area are quite minimal. In 2019, the change in 31 provinces and cities was more visible in a moderate disorder type; in the collecting space scenario, the spatial development pattern is eastern region > western northern region > northeast region > northeast region > northeast region > western region.

Thirdly, GTI and HQED in the eastern region are in good coordination and high-quality coordination, with Guangdong Province achieving excellent results. Green technology innovation is evident in the eastern area, which has experienced fast economic development. Green innovation technology has been adopted to promote sustainable economic development in environmental control. GTI and HQED are flourishing in the central and northeast regions, but GTI and HQED are on the edge of becoming unbalanced in the western area. All the western provinces and cities must fully mobilize resources from all parties, increase the efficiency of collaboration and assistance, and encourage the formation of a new pattern of coordinated development in this respect.

Fourthly, driving factors such as industrial structure, urbanization and economic development, R&D and foreign and education investment can promote coordinated development. At the same time, energy consumption intensity plays a role in inhibiting GTI and HQED.

This paper makes the following suggestions: (1) Establish clear HQED goals. There is a threshold effect on the ability of GTI to HQED, so it is necessary to avoid excessive development of GTI, consider the actual needs of the market and the overall degree of high-quality development, establish a scientific and reasonable high-quality development framework based on the development degree and ability of each province, and designate the corresponding departments to do a good job in supervision and management, and steadily promote high-quality development based on clear rights and responsibilities. (2) Incorporate green economic development into annual assessment indicators. There is a lot of room for improvement in the role of GTI in promoting HQED, but it is still necessary to give full play to the role of enterprise GTI. The goals of regional green economic development can be divided into the following categories: one is to solve outstanding ecological and environmental problems, the second is to promote transformation of the traditional industrial structure, the third is to promote development of local green industries, and the fourth is to improve the quality of the urban environment.

References

Acemoglu D., Gancia G., and Zilibotti F. (2012) Competing engines of growth: innovation and standardization. J Econ Theory 147(2):570–601

Ahmed W., and Najmi A. (2018) Developing and analyzing framework for understanding the effects of GSCM on green and economic performance. Manag Environ Quality Int J 29(4):740–758

Amidon, D.M. Innovation Strategy for the Knowledge Economy[J]. Long Range Planning, 1997,31(2):325-326.

Ariken, M., Zhang, F., Liu, K., Fang, C., and Kung, H. T. (2020). Coupling coordination analysis of urbanization and eco-environment in Yanqi Basin based on multi-source remote sensing data. Ecological Indicators, 114, 106331.https://doi.org/10.1016/j.ecolind.2020.106331

Banker R.D., Charnes A., and Cooper W.W. Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis[J]. Management Science, 1984, 30(9):1078-1092.

Braun, E., and Wield, D. Regulation as a means for the social control of technology[J]. Technology Analysis & Strategic Management, 1994, 6(3): 259-272.

Cai, X., Zhu, B., Zhang, H., Li, L., and Xie, M. (2020). Can direct environmental regulation promote green technology innovation in heavily polluting industries? Evidence from Chinese listed companies. Science of the Total Environment, 746, 140810. https://doi.org/10.1016/j.scitotenv.2020.140810

Chen Bin and Li Tuo. Have fiscal decentralization and environmental regulation promoted China's green technology innovation?[J]. Statistical Study, 2020,37 (06): 27-39.

Chen, S. Y., and Chen, D. K. (2018). Air pollution, government regulations and high-quality economic development. Econ. Res. J, 53, 20-34. https://doi.org/10.16538/j.cnki.jfe.20210615.201

Chen, Y., and Zhang, D. (2021). Multiscale assessment of the coupling coordination between innovation and economic development in resource-based cities: A case study of Northeast China. Journal of Cleaner Production, 318, 128597. https://doi.org/10.1016/j.jclepro.2021.128597

Deng Yuping, Wang Lun, and Zhou Wenjie. Does environmental regulation promote green innovation capacity?—— from empirical evidence from China [J]. Statistical Study, 2021,38 (07): 76-86.

Department of Research [J]. China Population, Resources and Environment, 2018,28 (04): 98-108.

Ding, L., Zhao, W., Huang, Y., Cheng, S., and Liu, C. (2015). Research on the coupling coordination relationship between urbanization and the air environment: A case study of the area of Wuhan. Atmosphere, 6(10), 1539-1558. https://doi.org/10.3390/atmos6101539

Du, B., Liu, Q., and Li, G. (2017). Coordinating leader-follower supply chain with sustainable green technology innovation on their fairness concerns. International Journal of Environmental Research and Public Health, 14(11), 1357.https://doi.org/10.3390/ijerph14111357

Fan Dan, and Sun Xiaoting. Environmental regulation, green technology innovation and green economic growth [J]. China Population Resources and Environment, 2020,30 (06): 105-115.

Gao, dynamic balance between green technology innovation and economic growth. Technology Square, 2021 (01): p. 65-76.

Ghisetti C., Rennings K.. Environmental innovations and profitability: how does it pay to be green? An empirical analysis of the German innovation survey[J]. Journal of Cleaner Production,2014, 75:106-117.

Goi, C.L. The impact of technological innovation on building a sustainable city. Int J Qual Innov 3, 6 (2017). https://doi.org/10.1186/s40887-017-0014-9

Guo Jin. Chinese evidence of the impact of environmental regulation on green technology innovation of the "Potter effect" [J]. Financial and trade economy, 2019,40 (03): 147-160.

Guo, Y., Xia, X., Zhang, S., and Zhang, D. (2018). Environmental regulation, government R&D funding and green technology innovation: Evidence from China provincial data. Sustainability, 10(4), 940.https://doi.org/10.3390/su10040940

He Zhili, Wang Fayuan, Wang Zongshun, and Hou Yuqiao. Green technology innovation, financial threshold and high-quality economic development are based on the Yangtze River Economic Belt [J]. Statistics and Decision-making, 2021,37 (19): 116-120.

Hua, L., and Yanling, D. (2021). China's High-quality Economic Development Level and the Source of Differences: Based on the Inclusive Green TFP Perspective. Journal of Finance and Economics, 47(08), 4-18.

Ji Zhiheng, Yu Wei, and Zhang Peng. The empirical evidence of the PVAR model is based on high-tech industrial spatial accumulation, technological innovation, and regional green development efficiency [J]. Macroeconomic Research, 2020 (09): 92-102.

Li Dan, and Yang Jianjun. Characteristics and characteristics of domestic green technology innovation literature and cutting-edge exploration [J]. Research management, 2015,36 (06): 109-118.

Li Nanbo, Gao Chenlei, and Zang Yuntai. Study on the Coupled Coordination Mechanism of Green Technology Innovation, Environmental Regulation and Green Finance [J]. Scientific Management Research, 2021,39 (02): 100-108.

Liao, K. C., Yue, M. Y., Sun, S. W., Xue, H. B., Liu, W., Tsai, S. B., and Wang, J. T. (2018). An evaluation of coupling coordination between tourism and finance. Sustainability, 10(7), 2320. https://doi.org/10.3390/su10072320

Luo, Q., Miao, C., Sun, L., Meng, X., and Duan, M. (2019). Efficiency evaluation of green technology innovation of China's strategic emerging industries: An empirical analysis based on Malmquist-data envelopment analysis index. Journal of Cleaner Production, 238, 117782.https://doi.org/10.1016/j.jclepro.2019.117782

Lynn, L.H., Reddy, N.M., and Aram, J.D. Linking technology and institutions: the innovation community framework[J]. Research policy, 1996, 25(1):p. 91-106.

MacLaurin W. R. The process of technological innovation: launching a new scientific industry[J]. The American Economic Review, 1950, (40)1:303-348.

Meirun, T., Mihardjo, L. W., Haseeb, M., Khan, S. A. R., and Jermsittiparsert, K. (2021). The dynamics effect of green technology innovation on economic growth and CO 2 emission in Singapore: New evidence from bootstrap ARDL approach. Environmental Science and Pollution Research, 28(4), 4184-4194. https://doi.org/10.1007/s11356-020-10760-w

Samad, G., and Manzoor, R. (2011). Green Growth: An Environmental Technology Approach. The Pakistan Development Review, 50(4), 471–490. http://www.jstor.org/stable/23617713

Shen, F., Liu, B., Luo, F., Wu, C., Chen, H., and Wei, W. The effect of economic growth target constraints on green technology innovation. J Environ Manage. 2021 Aug 15;292:112765. doi: 10.1016/j.jenvman.2021.112765. Epub 2021 May 20. PMID: 34022652.

Shi, T., Yang, S., Zhang, W., and Zhou, Q. (2020). Coupling coordination degree measurement and spatiotemporal heterogeneity between economic development and ecological environment----Empirical evidence from tropical and subtropical regions of China. Journal of Cleaner Production, 244, 118739.https://doi.org/10.1016/j.jclepro.2019.118739

Sun Yuhong, and Zhang Chunxiao. The Review and Thinking of China's Green Technology Innovation in the past 40 years of reform and opening [J]. Guangdong Social Sciences, 2018 (05): 5-12.

Tang, Z. (2015). An integrated approach to evaluating the coupling coordination between tourism and the environment. Tourism Management, 46, 11-19.https://doi.org/10.1016/j.tourman.2014.06.001

Tao Changqi, Li Cui, and Wang Xiahuan. The effect of environmental regulation on total factor energy efficiency and the evolution of energy consumption structure

Tao Feng, Zhao Jinyu, and Zhou Hao. Does environmental regulation achieve the "incremental quality improvement" of green technology innovation from the environmental target responsibility system [J]? China Industrial Economy, 2021 (02): 136-154.

Tovar, B. and Rendeiro Martín-Cejas, R. Technical efficiency and productivity changes in Spanish airports: A parametric distance functions approach[J]. Transportation Research Part E Logistics & Transportation Review, 2010, 46(2):249-260.

Wang Fayuan and Wang Zongshun. Green technology progress, financial input and high-quality economic development [J]. Statistics and Decision-making, 2021,37 (14): 109-112.

Wang Hui, Wang Xiaoqiao, Miao Zhuang, and Li Xiaocong. Heogenous threshold effect of R & D investment on green innovation efficiency based on China's high-tech industry [J]. Scientific research management, 2016,37 (02): 63-71.

Wang, Q., Qu, J., Wang, B., Wang, P., and Yang, T. (2019). Green technology innovation development in China from 1990 to 2015. Science of the Total Environment, 696, 134008.https://doi.org/10.1016/j.scitotenv.2019.134008

Wicki, S., and Hansen, E. G. (2019). Green technology innovation: Anatomy of exploration processes from a learning perspective. Business Strategy and the Environment, 28(6), 970-988.https://doi.org/10.1002/bse.2295

Xiao Liming, Gao Junfeng, Liu Shuai. Empirical Analysis of Interprovincial panel data based on spatial gradient [J]. Soft Science, 2017,31 (09): 63-68.

Xing, L., Xue, M., and Hu, M. (2019). Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: Case of Wuhan City in China. Journal of Environmental Management, 230, 474-487.https://doi.org/10.1016/j.jenvman.2018.09.065

Yang Haochang, Li Lianshui, and Zhang Invention. High-tech industrial agglomeration and green technology innovation performance [J]. Research management, 2020,41 (09): 99-112.

Zailani, S., Iranmanesh, M., Nikbin, D., and Jumadi, H. B. (2014). Determinants and environmental outcome of green technology innovation adoption in the transportation industry in Malaysia. Asian Journal of technology innovation, 22(2), 286- 301. https://doi.org/10.1080/19761597.2014.973167

Zhu Yuke, Gao Honggui, and Xiao Tian. Green technology innovation, industrial structure optimization and high-quality economic development of industrial enterprises [J]. Statistics and Decision-making, 2021,37 (19): 111-115.

Zhuang Qinqin, Wu Bin, and Hong Qunlian. Market-oriented green technology innovation system: theoretical connotation, practical exploration and promotion strategy [J]. The Economist, 2020 (11): 29-38.