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Original Research

The Coupling Coordination Evaluation and Influencing Factors Analysis of the Development of China's Digital Economy and the Construction of an Ecological Civilization

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Abstract

The coupling coordination between the development of the digital economy and the construction of an ecological civilization is an important topic for the high-quality coordinated development of China's economy and society. This study is based on panel data from 31 provinces and cities in China from 2013 to 2020. It utilizes the entropy method, coupling coordination degree model, and panel Tobit model to calculate the coupling coordination degree between the development of the digital economy and the construction of an ecological civilization, and to analyze the influencing factors. The results indicate that the overall coupling coordination degree of the two systems has been increasing year by year at the national level, with the development status transitioning from a mildly imbalanced state to a state on the brink of imbalance. The eastern region of China has the highest coupling coordination degree between the two systems, while the central and western regions both lag behind the national average, demonstrating a gradient decline in coupling coordination development across the eastern, central, and western regions. Urbanization, human capital, industrial structure, technological innovation, and government management have a significant positive impact on the coupling coordination degree of the two systems at the national level, while openness to the outside world has a significant negative impact. The impact of these influencing factors on the development of coupling coordination between the two systems exhibits significant heterogeneity across the eastern, central, and western regions, and each region should promote the development of coupling coordination based on local conditions, timing, and circumstances.

Keywords: digital economy; ecological civilization; coupling coordination; influencing factors

Introduction

Green, circular, and low-carbon development is an inevitable requirement for the construction of ecological civilization, while digital development serves as a crucial engine for achieving high-quality economic growth. Both represent the directions of the contemporary technological revolution and industrial transformation. At their core, the issues of ecological civilization construction fundamentally stem from adopting non-green and inefficient development and lifestyle patterns [1]. To address the challenges in ecological civilization

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construction, it is imperative to adhere to the principles of innovation, coordination, green development, openness, and shared growth [2]. This entails making digital transformation the driving force behind the transformation of production and lifestyle, identifying key areas where digital technology can empower ecological civilization construction, and accelerating the synergistic transformation of the economy and society towards digitization and green development. Digital economy not only represents a new growth point for the economy, but also serves as the support for the transformation and upgrading of traditional industries. Therefore, empowering ecological civilization construction through digitalization aligns with the trends and laws of digital economic development in the new era and offers a new path to modernize the ecological civilization construction system and governance capabilities. Currently, the development of the digital economy and the construction of ecological civilization, as major strategic objectives and important tasks in the development of Chinese society and economy in the new era, have made the coordinated development of these two domains a significant topic during the "14th Five-Year Plan" period. Consequently, it is of vital practical significance to scientifically calculate the coupling coordination degree between the development of the digital economy and the construction of ecological civilization, elucidate the influencing factors in their coordinated development, further enhance the regional ecological environment's carrying capacity, elevate the level of digital economic development, and respond to the goals of creating a Beautiful China and Digital China.

Research on the relationship between digital economic development and the construction of an ecological civilization is primarily focused on three main aspects. First, it involves a theoretical analysis of the mechanisms and pathways through which digital technology empowers the development of an ecological civilization. Scholars such as Chen et al. [3] argue that Marxism serves as the theoretical foundation for the empowerment of ecological civilization through digital technology. Digital technology, by altering the development mode, leading a green lifestyle, and facilitating ecological civilization governance, plays a pivotal role in empowering ecological civilization construction. On the other hand, Wu [2] emphasizes the digital challenges encountered in ecological civilization construction, including the difficulties in transitioning to a low-carbon development mode, inefficient ecological information circulation, and digital capital monopolies. Addressing these issues requires reinforcing technological innovation driven by digitalization and innovating the mechanisms of ecological civilization construction through digital means, promoting global collaboration in digitizing ecological construction. Secondly, the research delves into the coupled and coordinated development of digitization and greenization at both macro and micro levels. Some scholars incorporate ecological civilization into the framework of a green economic system [4], asserting that there exists a mutually supportive developmental relationship between digital economy and green economy. They argue that the synergistic development of these two sectors is an intrinsic requirement and inevitable choice for achieving high-quality and sustainable economic development in China [5]. In their work, Zhou and Qiao [6] measure the coupling coordination of greenization and digitization in 284 Chinese cities. They discover that the differences in coupling coordination across regions are primarily driven by inter-regional disparities, while the differences between northern and southern regions are mainly attributed to intra-regional variations. Government support and talent resources play crucial roles in promoting the deep integration of urban greenization and digitization. Thirdly, the research primarily offers a theoretical perspective on the coupling coordination mechanisms of digital economic development and ecological civilization construction. Liu [7] contends that by leveraging digital technology to empower ecological civilization construction, a green and intelligent digital ecological governance system can be established. This, in turn, supports the development of the digital economy while optimizing its structure and operational mechanisms. The coordinated development of the digital economy and ecological civilization enhances both the level of digital economic development and the capacity for ecological governance, ensuring their synchronous advancement with the national modernization level. Additionally, some scholars propose the concept of a "Chinese-style digital ecosystem," highlighting that the creation of a favorable digital ecosystem should begin with practices in digital production and green living. This approach aims to achieve a circular relationship among digital technology, ecology, production, and lifestyle [8].

Existing research has provided some reference regarding the coordinated development of the digital economy and ecological civilization. However, there are still certain shortcomings, as the existing studies tend to lean heavily toward theoretical analysis, lacking sufficient quantitative analysis. Given this, the primary marginal contributions of this paper are as follows: First, for the first time, it integrates the development of the digital economy and the construction of ecological civilization into a unified research framework. It innovatively constructs an evaluation system for the coupling coordination between the development of the digital economy and the construction of ecological civilization and calculates the coupling coordination degree. This serves as a reference for subsequent research. Second, by employing a panel Tobit model, it regionally examines the influencing factors of the coupling coordination between the development of the digital economy and the construction of ecological civilization, thereby offering theoretical guidance for advancing the coordinated development of the two systems in different regions.

The structure of this paper is as follows: Section 2 provides an overview of the research methodology and the system of indicators employed in this study. Section 3 conducts an analysis and discussion of the research findings. Section 4 presents the main conclusions drawn and proposes policy recommendations.

Experimental

Study Design

Entropy Method

Standardizing the indicators can eliminate the influence of dimensional issues among the data on the results. The specific formula is as follows:

Positive indicators: $x_{ij}^{'} = \frac{x_{ij} - min(x_{ij})}{max(x_{ij}) - min(x_{ij})}$ (1)

Negative indicators: $x_{ij}^{'} = \frac{max(x_{ij}) - x_{ij}}{max(x_{ij}) - min(x_{ij})}$ (2)

After standardizing the data, the entropy method is employed to assign weights to each indicator. First, the proportion P_{ij} of the indicator value of the i_{th} evaluated object under the j_{th} indicator is calculated:

$$P_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m} x_{ij}} \quad (3)$$

Secondly, calculate the information entropy E_j using the following formula:

$$E_j = -k \sum_{i=1}^{m} P_{ij}\, ln(P_{ij}) \; (i = 1,2,3,\cdots,m; j = 1,2,3\cdots,n) \quad (4)$$

Where $k = \frac{1}{ln\, m}$， $\frac{1}{ln\, m} \geq 0$， and if $P_{ij}=0$，

then $\lim_{P_{ij}\to 0} P_{ij} \ln P_{ij} = 0$。

Finally, calculate the weights of the indicators W_j using the formula: $W_j = \frac{1-E_j}{\sum_{j=1}^{n} 1-E_j}$ $(0 \leq W_j \leq 1)$ (5)

comprehensive evaluation model

Calculate the index of digital economic development and ecological civilization construction using the formula:

$$U_j = \sum_{j=1}^{m} W_j x_{ij}^{'} \quad (6)$$

W_j represents the weights of each indicator, x_{ij}' stands for the standardized values of each indicator, and U_j denotes the evaluation value of each subsystem.

Entropy Weight TOPSIS Method

The Entropy weighted TOPSIS method is an improved approach based on the Entropy method for traditional TOPSIS, which can help mitigate the impact and bias caused by subjective factors to some extent [9]. It determines the index of digital economic development and ecological civilization construction by calculating the solutions that are closest to the positive ideal solution and farthest from the negative ideal solution.

Coupling Coordination Model

The Coupling Coordination model effectively overcomes the drawback of traditional coupling degrees, which tend to indicate higher coupling even when the comprehensive evaluation values of a system are relatively low, and better reflects the overall level of coupling coordination in a system [10]. Therefore, in this paper, we employ the Coupling Coordination model to calculate the coupling coordination degree between the development of the digital economy and the construction of ecological civilization, with the specific formula as follows:

$$C = \left\{\frac{U_1 \times U_2}{[(U_1+U_2)/2]^2}\right\}^{\frac{1}{2}} \quad (7)$$

$$T = \alpha_1 U_1 + \alpha_2 U_2 \quad (8)$$

$$Y = \sqrt{CT} \quad (9)$$

In the formula, C represents coupling degree, T stands for inter-system coordination index, α1, and α2 are undetermined weights for the two systems. In the evaluation process, both systems are considered equally important, and thus, α1 = α2 = 0.5. Y represents the coupling coordination degree. Following the existing classification results, the coupling coordination degree between the development of the digital economy and the construction of ecological civilization is categorized into three major classes and ten subcategories [11], as shown in Table 1.

Table 1. Coupling Coordination Degree Classification

Type of coordination	Degree of Coupling Coordination	Y-value Range of Coupling Coordination	Type of coordination	Degree of Coupling Coordination	Y-value Range of Coupling Coordination
Dysfunctional recession category	Extreme dislocation	（0.0—0.1）	Overdevelopment category	Forced coordination	[0.5—0.6）
	Severe dislocation	[0.1—0.2）	Coordinated development category	Primary coordination	[0.6—0.7）
	Moderate dislocation	[0.2—0.3）		Intermediate coordination	[0.7—0.8）
	Mild dislocation	[0.3—0.4）		Good coordination	[0.8—0.9）
Overdevelopment category	Imminent dislocation	[0.4—0.5）		Quality coordination	[0.9—1.0）

Panel Tobit Model

The Tobit model, also known as the sample model or limited dependent variable model, is suitable for situations where the dependent variable has zero values while other values are positive and continuous [12]. Since the coupling coordination degree between the development of the digital economy and the construction of ecological civilization falls between 0 and 1, it is considered a bounded variable. If traditional ordinary least squares estimation is used, it may lead to biased and inconsistent parameter estimates. The use of the panel Tobit model can better address this issue. The formula is as follows:

$$\begin{cases} y_{it}^{*} = \alpha + \beta x_{it} + u_i + \varepsilon_{it}, y_{it}^{*} > 0 \\ 0, y_{it}^{*} \leq 0 \end{cases} \quad (10)$$

In the equation: y^{*}_{it} represents the truncated variable; x_{it} represents the independent variables; α is the intercept term; β is the regression parameter value; u_i represents individual effects; and ε is the random error term, which is independent and follows a normal distribution.

Data Sources and Construction of Indicator System

Data Sources

The panel data used in this study, covering the years 2013 to 2020, is sourced from various official publications including the *China Statistical Yearbook* (2014-2021), *China Energy Statistical Yearbook*, *China Environmental Statistical Yearbook,* and the EPS database. The Digital Inclusive Finance Index is derived from the *Peking University Digital Inclusive Finance Index (2011-2020)*. Data for indicators such as per capita arable land area and per capita forest area were calculated based on information provided in the yearbooks and the database. Additionally, the classification of China into eastern, central, and western regions follows the standards outlined in the *China Statistical Yearbook 2021*.

Table 2. Coupling Coordination Evaluation Indicator System for Digital Economic Development and Ecological Civilization Construction

target level	Subsystem level	indicator layer	Direction of Indicators
Digital Economy System	Digital facility	Length of communication fiber-optic cable lines (km)	+
		Number of Internet domain names (ten thousand)	+
		Number of telephone base stations (ten thousand)	+
		Number of Internet broadband access subscribers (ten thousand)	+
	Digital industrialization	Number of digital TV subscribers (ten thousand)	+
		Revenue from main business of telecommunication industry (billions)	+
		Business income from software industry (billions)	+
		E-commerce sales (billions)	+
	Industrial digitization	Number of enterprise informatization units (units)	+
		Websites per 100 enterprises (number)	+
		Number of enterprises with e-commerce trading activities (number)	+
		Digital Inclusive Finance Index	+
Ecological Civilization System	Resource utilization	Per Capita Arable Land Area (Thousand Hectares)	+
		Per Capita Forest Area (Ten Thousand Hectares)	+
		Per Capita Water Resource Stock (cubic meters per person)	+
		Comprehensive Industrial Solid Waste Utilization Quantity (ten thousand tons)	+
	Environmental governance	Industrial Exhaust Gas Treatment Capacity (ten thousand cubic meters per hour)	+
		Rate of Harmless Treatment of Domestic Garbage (%)	+
		Urban Wastewater Treatment Rate (%)	+
		Urban Household Garbage Removal Quantity (ten thousand tons)	+
		Urban Exhaust Gas Emission Volume (ten thousand tons)	-
		Urban Wastewater Discharge Volume (ten thousand cubic meters)	-
		Industrial Solid Waste Generation (ten thousand tons)	-
	ecological construction	Proportion of Clean Energy Electricity Generation to Total Electricity Generation (%)	+
		Electricity Generation per ten thousand Yuan of Gross Domestic Product (KW/ten thousand Yuan)	+
		Proportion of Investment in Ecological and Environmental Pollution Control to GDP (%)	+

Indicator System Construction

Digital economic development and ecological civilization construction involve multiple dimensions, and the assessment of each system's development level using single-dimensional indicators can be challenging in accurately and comprehensively representing their progress. In accordance with the statistical classification of the digital economy and its core industries released by the National Bureau of Statistics, and in conjunction with current academic references on the construction of digital economic indicators [10, 13, 14], this paper posits that digital infrastructure forms the foundation for the development of the digital economy, providing both physical and technological support. Given the multifaceted nature of digital infrastructure, the paper employs four indicators, including communication cable length and network domain count, for assessment. The paper asserts that digital industrialization is the cornerstone of digital economic development, serving as the direct intrinsic driver. Consequently, three indicators, such as the number of digital television users and telecommunications main business revenue, are utilized for measurement. Additionally, the paper considers industrial digitization as a 'catalyst' for digital economic development, providing application scenarios. To evaluate this, five indicators, including e-commerce sales and the number of enterprises undergoing informatization, are employed. For the construction of the ecological civilization evaluation system, in accordance with the 'Opinions of the Central Committee of the Communist Party of China and the State Council on Accelerating the Promotion of Ecological Civilization Construction' and referencing current academic research on ecological civilization construction [15, 16], the paper proposes that ecological civilization construction should focus on three aspects: resource allocation, direct environmental governance, and ecological development. The aim is to achieve sustained improvement in the ecological environment, enhance the robustness of ecological security barriers, and noticeably improve urban and rural living environments. Accordingly, by referring to current academic research on ecological civilization construction [13, 14], a total of 14 indicators across three dimensions—resource utilization, environmental governance, and ecological development—are employed to construct the ecological civilization evaluation indicator system, as illustrated in Table 2.

Results

Analysis of the Development Levels of Digital Economy and Ecological Civilization Construction

After normalizing the indicators for digital economic development and ecological civilization construction, the Entropy method was employed to calculate the National Digital Economic Development and Ecological Civilization Construction Development Indices for the 31 provinces and municipalities in China from 2013 to 2020. The average overall development index for the nation and the average regional development indices for the eastern, central, and western regions were also determined, as shown in Table 3. From a national perspective, both digital economic development and ecological civilization construction levels have shown an upward trend. The Digital Economic Development Index increased from 0.11 in 2013 to 0.25 in 2020, representing a growth of 127.27%. The Ecological Civilization Construction Index rose from 0.13 in 2013 to 0.16 in 2020, indicating a 23.08% increase. In 2015, the Digital Economic Development Index surpassed the Ecological Civilization Construction Index, marking a shift from an ecological civilization-driven model with lagging digital economic development to a model where digital economic development takes the lead with ecological civilization development lagging behind. This shift is primarily attributed to the complex and long-term nature of ecological civilization construction, involving deep-rooted contradictions accumulated over the course of long-term economic and social development [17]. Relative to digital economic development, ecological civilization construction exhibits lower efficiency and longer cycles. As a result, ecological

Table 3. Digital Economic Development and Ecological Civilization Construction Index

Year	Digital Economic Development Index				Ecological Civilization Development Index			
	National	Eastern region	Central region	Western region	National	Eastern region	Central region	Western region
2013	0.11	0.20	0.09	0.05	0.13	0.09	0.11	0.18
2014	0.13	0.23	0.10	0.06	0.13	0.09	0.11	0.18
2015	0.16	0.27	0.13	0.08	0.14	0.10	0.11	0.19
2016	0.18	0.30	0.15	0.09	0.14	0.11	0.12	0.19
2017	0.20	0.32	0.16	0.10	0.16	0.13	0.13	0.20
2018	0.21	0.35	0.18	0.12	0.16	0.12	0.13	0.20
2019	0.24	0.38	0.20	0.13	0.16	0.13	0.15	0.20
2020	0.25	0.41	0.21	0.15	0.16	0.12	0.15	0.20

civilization development, which originally operated at a relatively high level, has gradually fallen behind digital economic development. Furthermore, both the overall level of China's Digital Economic Development Index and Ecological Civilization Construction Index are relatively low. On one hand, this is attributed to the belated inclusion of the digital economy in the Chinese government's work report in 2017. The digital infrastructure development lags behind, industrial digitization is undergoing a transformative phase, and the digital industry is still in its formative stage. Consequently, the Digital Economic Development Index exhibits a relatively low level. On the other hand, while China has consistently prioritized environmental protection, systematic planning and emphasis on target tasks were not implemented before 2016. This resulted in a relatively lower level of development. Post-2016, with the formulation of the 'Thirteenth Five-Year Plan,' ecological civilization construction was identified as one of the primary objectives of economic and social development. As a result, the Ecological Civilization Construction Index has shown a gradual improvement.

From a regional perspective, in the eastern region, the Digital Economic Development Index increased from 0.20 in 2013 to 0.41 in 2020, marking a growth of 105%, while the Ecological Civilization Construction Index rose from 0.09 in 2013 to 0.12 in 2020, a 33.33% increase. This indicates a development pattern where digital economic development leads, and ecological civilization lags behind. In the central region, the Digital Economic Development Index increased from 0.09 in 2013 to 0.21 in 2020, with a growth rate of 133.33%, while the Ecological Civilization Construction Index rose from 0.11 in 2013 to 0.15 in 2020, a 27.27% increase. This shift represents a transition from an ecological civilization-driven model with lagging digital economic development to a model where digital economic development takes the lead, and ecological civilization lags behind. In the western region, the Digital Economic Development Index increased from 0.05 in 2013 to 0.15 in 2020, a growth of 200%, while the Ecological Civilization Construction Index increased from 0.18 in 2013 to 0.20 in 2020, marking an 11.11% increase. The development pattern in this region is characterized by ecological civilization leading and digital economic development lagging. Overall, the levels of digital economic development and ecological civilization construction in the eastern, central, and western regions exhibit contrasting development patterns. Specifically, the level of digital economic development follows a gradient decrease from the eastern region to the western region, while the level of ecological civilization construction demonstrates a gradient increase from east to west. The fundamental reason for the formation of such a pattern lies in the relatively higher economic development level in the eastern region, contributing to a higher Digital Economic Development Index. However, due to a larger population and relatively scarce natural resources, ecological civilization construction lags behind in this region. Conversely, the western region exhibits a lower level of economic development, resulting in a relatively slower pace of construction in digital technological facilities and industrial digitization transformation. Consequently, the Digital Economic Development Index is comparatively lower in the western region. Nonetheless, the western region possesses abundant natural resources and serves as a crucial barrier for China's ecological security. As a result, the Ecological Civilization Construction Index is relatively higher in the western region.

Analysis of the Coupling Coordination of Digital Economic Development and Ecological Civilization Construction

Using the Coupling Coordination Degree, the coupling coordination degree between digital economic development and ecological civilization construction for the 31 provinces and municipalities in China from 2013 to 2020 was calculated. The average coupling coordination degrees for the entire nation and the eastern, central, and western regions were determined, as presented in Table 4 and Figure 1. From a national perspective, the coupling coordination degree between the two systems shows an upward trend, indicating progress, but it remains at a relatively low level. It has not achieved a fully coordinated development. The average coupling coordination degree increased from 0.32 in 2013 (indicating a mild imbalance) to 0.45 in 2020 (bordering on a state of imbalance), representing a 40.63% increase. This suggests that, at the national level, there is still insufficient attention given to the coordinated development of digital economic development and ecological civilization construction. The extensive development model has not been effectively improved, and digital technology has not been fully utilized in the process of ecological protection. Therefore, further integration and enhancement of digital economic development and ecological civilization construction are required.

Table 4. The Coupling Coordination of Digital Economy Development and Ecological Civilization Construction in the Whole Country and the East-Central Region

Regional	2013	2014	2015	2016	2017	2018	2019	2020
National	0.32	0.34	0.36	0.39	0.42	0.42	0.44	0.45
Eastern region	0.34	0.36	0.38	0.41	0.46	0.45	0.47	0.47
Central region	0.31	0.33	0.35	0.38	0.40	0.41	0.44	0.45
Western region	0.30	0.32	0.35	0.37	0.39	0.40	0.42	0.43

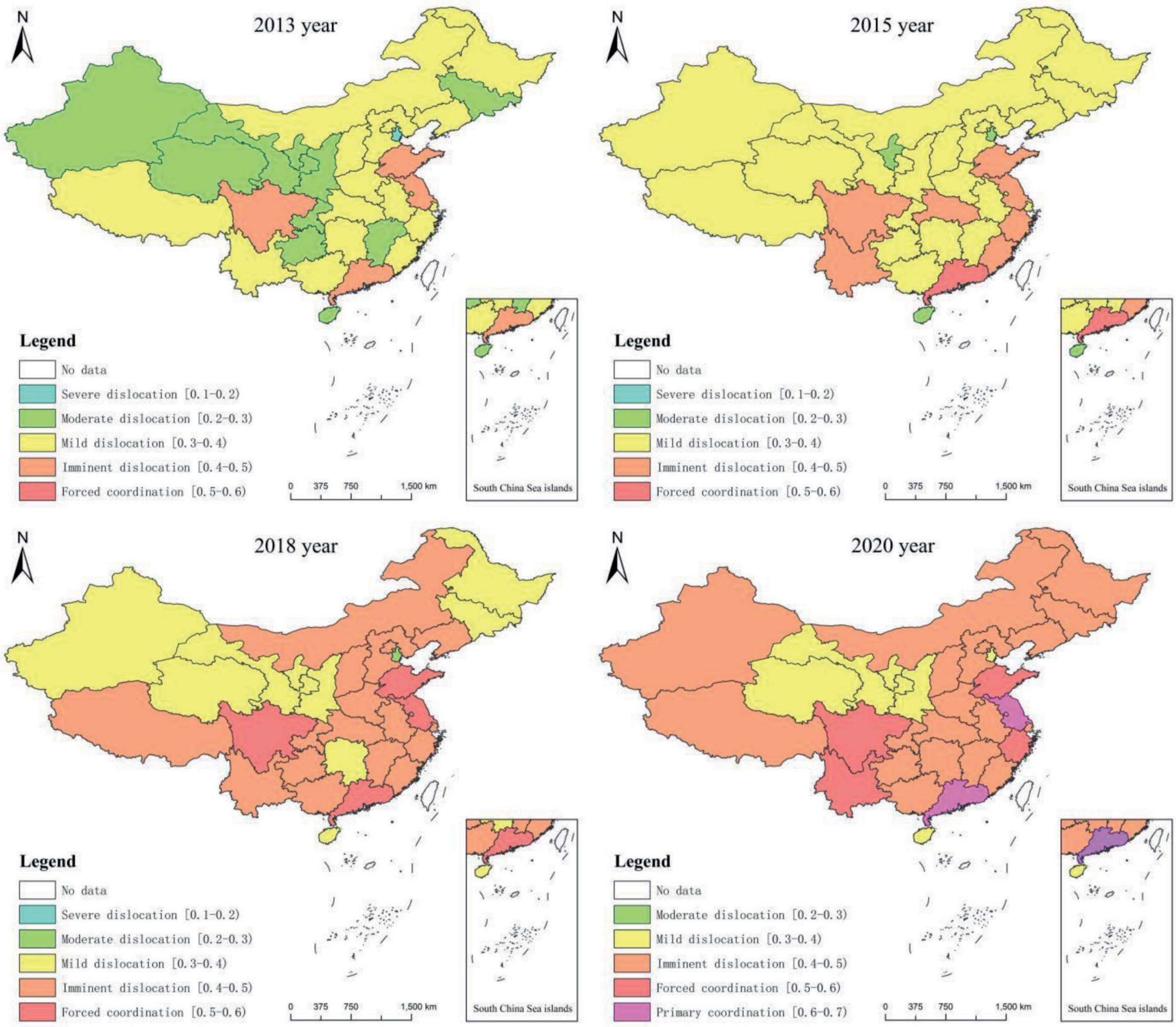

Fig. 1. Provincial Digital Economy Development and Ecological Civilization Construction Coupling Coordination

From a regional perspective, the coupling coordination degree between the two systems in the eastern, central, and western regions shows an upward trend, but they have not yet achieved a fully coordinated development. In the eastern region, the average coupling coordination degree increased from 0.34 in 2013 (indicating a mild imbalance) to 0.47 in 2020 (bordering on a state of imbalance), marking a 38.24% increase. In the central region, the average coupling coordination degree increased from 0.31 in 2013 (indicating a mild imbalance) to 0.45 in 2020 (bordering on a state of imbalance), showing a 45.16% increase. In the western region, the average coupling coordination degree increased from 0.30 in 2013 (indicating a mild imbalance) to 0.43 in 2020 (bordering on a state of imbalance), representing a 43.33% increase. The eastern region has the highest coupling coordination degree between the two systems, while the central and western regions lag behind the national average. The overall trend in coupling coordination degree between the two systems exhibits a gradient decrease from the eastern to the central and western regions.

Looking at individual provinces and cities, in 2013, most provinces and cities had their two systems in a state of moderate or mild imbalance. Only four provinces - Shandong, Jiangsu, Guangdong, and Sichuan - were bordering on an imbalance state. Among these, Guangdong had the highest coupling coordination degree between the two systems at 0.47. By 2015, the number of provinces bordering on an imbalance state increased, but only Guangdong achieved coordinated development with a coupling coordination degree of 0.51. In 2018, four provinces - Shandong, Jiangsu, Guangdong, and Sichuan - achieved coordinated development. Jiangsu and Guangdong had the highest coupling coordination degrees among these. Tianjin had a coupling coordination degree of 0.27, still in a state of moderate imbalance. In 2020, Jiangsu and Guangdong reached a primary level of coordination, and four provinces - Shandong, Zhejiang, Sichuan, and Yunnan - achieved a marginal level of coordination. Jiangsu had the highest coupling coordination degree of 0.67. Additionally, there were six provinces and cities - Tianjin, Hainan, Shaanxi, Gansu, Qinghai, and Ningxia - in a state of mild imbalance,

Table 5. Factors Influencing the Coupling and Coordinating Degree of Digital Economic Development and Ecological Civilization Construction

Variable Name	Variable Symbol	Variable Description	Unit of Measurement
Urbanization	Un	Urbanization Rate	%
Human Capital	Edu	Number of Graduates from Higher Education Institutions	person
Industrial Structure	Indu	The Proportion of the Tertiary Sector in the Regional Gross Domestic Product (GDP)	%
Technological Innovation	Pat	Full-Time Equivalent Research and Development (R&D) Personnel	Year
Openness to Foreign Markets	Open	Share of Foreign-Invested Enterprises' Import and Export Value in Regional Gross Domestic Product	%
Government Management	Gov	Share of Regional Fiscal Expenditure in Regional Gross Domestic Product	%

with Tianjin and Hainan having the lowest coupling coordination degrees, both at 0.30. It is evident that, as time progressed, more provinces achieved coordinated development between the two systems, and both eastern and western regions had areas with significant growth in the coupling coordination of the two systems. This suggests that the two systems in the eastern and western regions have different development stages and their respective comparative advantages. The eastern region has a strong foundation for digital economic development but faces constraints related to resource and environmental bottlenecks. The western region, on the other hand, has abundant natural resources but lags significantly behind the eastern region in terms of economic strength, talent pool, and industrial base. Therefore, the marginal effects of coupling coordination development are more pronounced in certain provinces and cities in both eastern and western regions. A regional development pattern with a focus on coordinated development between the two systems is gradually emerging.

Analysis of Factors Affecting the Coupling Coordination of Digital Economy Development and Ecological Civilization Construction

Selection of Influencing Factors

The coupling coordination of digital economic development and ecological civilization construction is a complex systemic project influenced by various factors in the economic and social context. Urbanization has the potential to propel the rapid ascent of the digital economy, but may also trigger over-exploitation of resources. The cultivation and recruitment of technical talent can foster innovation and technological progress, providing a foundational support for the development of the digital economy and ecological civilization construction. Industrial restructuring promoting the development of green industries may result from adjusting the industrial structure, yet addressing social issues arising from the transition of traditional industries is imperative. Technological innovation serves as the driving force for both the digital economy and ecological civilization construction, though attention must be paid to the environmental risks associated with technological applications. Openness to the outside world facilitates international cooperation in the digital economy, but it may also encounter challenges related to resource competition and environmental spillover. Government management plays a pivotal role in coordinating the development of the digital economy and ecological civilization construction. Therefore, achieving the coupled coordination of digital economic development and ecological civilization construction requires a comprehensive consideration of various factors, including urbanization, human capital, industrial structure, technological innovation, openness to the outside world, and government management. In light of these considerations, referencing existing literature [11, 18, 19, 20, 21], urbanization, human capital, industrial structure, technological innovation, openness to the outside world, and government management indicators are characterized. The Tobit model is employed to elucidate the impact of each factor on the coupled coordinated development of the two systems. Specific variable settings are detailed in Table 5.

Regression Results Analysis

Due to the Tobit model with fixed effects lacking sufficient statistical information to identify individual heterogeneity, it is not possible to perform conditional maximum likelihood estimation as is done in count models. When introducing dummy variables into mixed Tobit regression, the fixed effects estimates obtained are biased. Therefore, only mixed Tobit regression and random Tobit regression are considered. The LR test for Model 1 is 301.61 with a p-value of 0.00, indicating the use of a random panel Tobit model for regression. The regression results for Model 1 are presented in Table 6.

Specifically, urbanization has a coefficient of 0.6667 with a significance level of 1%, indicating that urbanization is favorable for the coupled development of digital economy and ecological civilization. The reason for this may lie in the fact that the new urbanization strategy emphasizes the importance of resource conservation and environmental friendliness alongside new infrastructure construction, thereby balancing the development priorities of both systems, making it one of the core influencing factors for the coupled development of the two systems. Human capital has a coefficient of 0.1382 with a significance level of 1%, demonstrating that an improvement in human capital can effectively drive the coupled development of the digital economy and ecological civilization. This occurs by accelerating the concentration of talent in the region, enhancing human capital stock and quality, improving the quality of ecological environment governance, and increasing the efficiency of digital economic development. The coefficient for industrial structure is 0.4707 with a significance level of 1%. This indicates that optimizing industrial structure can guide industries towards digitization, green development, and high value addition, effectively improving resource utilization efficiency and reducing the interference and disruption of regional economic and social development in the ecological environment. Moreover, it can expedite industrial concentration in the region, the formation of digital industries, and the transformation to digital industrialization, thus promoting the coupled development of the two systems. The coefficient for technological innovation is 0.0563 with a significance level of 10%. This suggests that an improvement in the level of technological innovation has a significant promoting effect on the coupled development of the two systems. This can be achieved by accelerating technological innovation and the development of high-tech industries, promoting the formation and development of regional digital industries, facilitating the upgrading of regional industrial digitization, and accelerating the modernization of ecological environment governance. Foreign trade's coefficient is -0.0228 with a significance level of 1%. This indicates that expanding foreign trade and attracting foreign investment do not promote the coupled development of the digital economy and ecological civilization. On one hand, foreign investment brings in a substantial amount of technology and capital, generating spillover and demonstration effects, thereby promoting the development of the digital economy. On the other hand, the influx of foreign capital locks regional industries into low-value segments of the industrial chain, further inhibiting the formation of regional digital industries and the improvement of the ecological environment. These interactions highlight the negative impact of foreign trade. The coefficient for government management is 0.2058 with a significance level of 1%, indicating that government management plays a positive role in the coupled development of the two systems. Government macroeconomic regulation has inherent advantages in the free flow and rational allocation of resource elements. Therefore, by fully leveraging the government's role in macroeconomic control, it can effectively prevent the coupled development of the two systems from falling behind and getting locked due to market failure.

Robustness Test

To ensure the reliability of the research results, this study conducted robustness tests by altering the statistical methods of the dependent variable, replacing explanatory variables, and adding explanatory variables [22,23]. In these tests, the entropy-weighted Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was used to calculate the coupled coordination degree of the two systems instead of the entropy method. The number of students enrolled in regular higher education institutions was used to measure human capital (Edu) in place of the number of higher education graduates. Additionally, provincial road density was introduced as a variable representing transportation infrastructure (Inf) in

Table 6. Regression Results and Robustness Test Results

Variables	Model 1	Model 2	Model 3
LnUn	0.6667*** (5.65)	0.7784*** (5.78)	0.7135*** (5.62)
LnEdu	0.1382*** (2.92)	0.1093** (2.18)	0.1381*** (2.60)
LnIndu	0.4707*** (6.26)	0.3997*** (4.70)	0.5152*** (6.58)
LnPat	0.0563* (1.79)	0.0586* (1.67)	0.0777** (2.38)
LnOpen	-0.0228*** (-2.20)	-0.0322*** (-2.83)	-0.0184* (-1.79)
LnGov	0.2058*** (3.67)	0.1697*** (2.67)	0.1842*** (3.23)
LnInf	-	-	-0.0605* (-1.70)
Cons	2.2628*** (4.30)	2.4446*** (4.40)	3.0196*** (7.93)
Log likelihood	255.9365	227.7436	254.7825
N	248	248	248

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

the regression model for analysis [24]. The specific results are presented in Table 6. Model 2 had an LR test statistic of 278.50 with a p-value of 0.00, and Model 3 had an LR test statistic of 264.90 with a p-value of 0.00. Both models employed the random panel Tobit model for regression. Model 2 was designed as the test model for altering the statistical methods of the dependent variable, while Model 3 was created for the replacement of explanatory variables and the addition of explanatory variables. It is observed that the regression coefficients in Models 2 and 3 remained relatively stable, and the direction of the regression coefficients did not change, providing results consistent with the regression outcomes of Model 1. Furthermore, transportation infrastructure (Inf) exhibited a significant negative impact on the coupled coordination degree of the two systems in both Models 2 and 3. Hence, the regression results in Model 1 demonstrate stability.

Regional Heterogeneity Analysis

Regional heterogeneity analysis was conducted separately for the Eastern, Central, and Western regions. For the Eastern region, the LR test statistic was 60.89 with a p-value of 0.00. In the Central region, the LR test statistic was 0.34 with a p-value of 0.28. In the Western region, the LR test statistic was 153.29 with a p-value of 0.00. Random panel Tobit regression, mixed Tobit regression, and random Tobit regression were employed for these analyses, and the regression results are presented in Table 7.

Specifically, in the Eastern region, human capital and industrial structure have a significantly positive impact on the coupling coordination of the two systems, while openness to foreign investment has a significant negative impact. This suggests that the Eastern region should further optimize its industrial structure, enhance the quantity and quality of human capital, and create world-class digital industry hubs and talent development platforms to lead the coordinated development of the two systems. However, when attracting foreign investment, a comprehensive assessment of the relationship between 'attracting talent' and 'attracting investment' should be considered based on the specific circumstances and opportunities. In the Central region, urbanization, human capital, industrial structure, government management, and transportation infrastructure all have a significantly positive impact on the coupling coordination of the two systems. This indicates that in the Central region, the coordinated development of the two systems requires a balanced consideration of various factors and harnessing the combined effects of different drivers. The impact of technological innovation is not significant, suggesting that the Central region should further promote the integration of green and digital technologies in the coordinated development of the two systems to strengthen the role of technological innovation. In the Western region, urbanization, human capital, industrial structure, and government management all have a significantly positive impact on the coupling coordination of the two systems, while transportation infrastructure has a significant negative impact. This implies that the Western region should focus on enhancing urbanization, human capital, and industrial factors in promoting the coordinated development of the two systems. However, attention should be paid to the rational layout of transportation infrastructure development and investments in environmental governance to mitigate the direct and indirect impacts of transportation infrastructure on the regional ecological environment.

Table 7. Regional Heterogeneity Regression Results

Variables	Eastern region	Central region	Western region
LnUn	-0.5717 (-1.35)	0.8950*** (6.79)	0.8791*** (10.61)
LnEdu	0.2898** (2.53)	0.1404*** (2.79)	0.1364*** (3.44)
LnIndu	1.2324*** (5.67)	0.2560*** (3.37)	0.4072*** (6.68)
LnPat	0.0410 (0.56)	0.0080 (0.13)	0.0037 (0.12)
LnOpen	-0.1235*** (-2.85)	-0.0526*** (-3.06)	0.0003 (0.04)
LnGov	-0.0875 (-0.79)	0.1545*** (4.07)	0.1402** (2.03)
LnInf	0.0447 (0.36)	0.1755*** (3.83)	-0.0508* (-1.86)
Cons	-0.1363 (-0.13)	2.9173*** (7.40)	2.8821*** (5.72)
Log likelihood	78.5905	100.9120	163.8949
N	87	64	96

`Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Conclusions

This study, based on panel data from 31 provinces and cities in China from 2013 to 2020, employed the entropy method and coupling coordination model to assess the coupling coordination of digital economic development and ecological civilization construction. Additionally, it utilized the panel Tobit model to analyze the influencing factors of the coupling coordination between digital economic development and ecological civilization construction. The primary research findings are as follows:

(1) From a national perspective, the overall trend in the Digital Economic Development Index, Ecological Civilization Construction Index, and the coupled coordination degree of the two systems exhibits a fluctuating upward trajectory. The development pattern has transitioned from ecological civilization construction predominantly leading digital economic development, resulting in a lag, to digital economic development predominantly leading ecological civilization with a subsequent lag. The developmental status has shifted from a state of mild imbalance to a state on the brink of imbalance. The two systems have not achieved coordinated development, necessitating further integration and enhancement. At the regional level, the Digital Economic Development Index, Ecological Civilization Construction Index, and the coupled coordination degree of the two systems in the eastern, central, and western regions also demonstrate a fluctuating upward trend. The Digital Economic Development Index reveals a gradient decrease from the eastern to the western regions, while the Ecological Civilization Construction Index exhibits a gradient increase from the eastern to the western regions. The coupled coordination degree of the two systems is highest in the eastern region, while both the central and western regions lag behind the national average. None of the three major regions has achieved coordinated development, and the overall pattern of the coupled coordination degree shows a gradient decrease from the eastern to the western regions. Notably, there are significant regional differences in the coupled coordinated development between provinces and cities, with provinces in both eastern and western regions displaying coordinated development of the two systems.

(2) Regarding the influencing factors, urbanization, human capital, industrial structure, technological innovation, and government management exhibit significant positive effects on the coupling coordination of the two systems at the national level. On the other hand, openness to foreign investment has a significant negative impact on the coupling coordination of the two systems. In the Eastern region, emphasis should be placed on optimizing regional industrial structure and enhancing human capital to drive the coordinated development of the two systems. Meanwhile, in the Central and Western regions, there should be a focus on the cumulative effects of various factors contributing to the coupling coordination of the two systems. Additionally, regions should consider the heterogeneity in the effects of openness and transportation infrastructure on the coordinated development of the two systems and should tailor their approaches based on local conditions and circumstances.

Based on the above conclusions, the following countermeasures are proposed:

(1) In response to the challenges of low Digital Economic Development Index and Ecological Civilization Construction Index, provinces should integrate and share diverse ecological civilization data, providing multisource and multiscale data support to enhance the timeliness and availability of ecological civilization governance data. It is imperative to improve the supervision and governance mechanisms for ecological civilization by utilizing digital ecological models and simulation platforms to predict the evolutionary trends of the ecological civilization system, effectively safeguarding the "green waters and lush mountains". Intensifying efforts in the construction of digital infrastructure, as well as strengthening initiatives for talent cultivation and technological research and development, are essential to provide intellectual support for the development of the digital economy. Addressing the issue of the lack of coordinated development between the two systems, provinces should establish an awareness of the deep integration of the digital economy and ecological civilization, reinforcing the advocacy, implementation, and execution of the integration development concept of the digital economy and ecological civilization. It is crucial to comprehensively enhance the networked, intelligent, and collaborative levels of environmental infrastructure, establishing platforms for sharing ecological civilization data and ecological asset databases. To achieve this, it is necessary to construct a market-oriented green technology innovation system that guides the green transformation of production, distribution, and consumption patterns, leading the growth of industries such as energy conservation and environmental protection, clean production, clean energy, and green services.

(2) Address the problem of regional differences in the coupling coordination of the two systems. The coupled and coordinated development of digital economy development and ecological civilization construction should be promoted in a classified and hierarchical manner, and it is difficult to break the imbalance in the coupled and coordinated development of digital economy development and ecological civilization construction in the short term, due to the impact of the imbalance in long-term economic development and resource factor distribution. Therefore, provinces and cities with high degree of coupling coordination between the two systems should further enhance their technological innovation capacity and resource

optimization and allocation capacity, strengthen their radiation-driven role in regional development, and accelerate the creation of the first echelon leading the coupled and coordinated development of the two systems. Provinces and cities with a low degree of coordination between the two systems should do a good job in the top-level design of the coordinated development of the two systems, optimize the setup of administrative divisions, break down the barriers to resource flows, enhance the carrying capacity of the economy and the population, and give full play to their own strengths in the basic support for the coupled and coordinated development of the two systems. To address the problem of heterogeneity of factors influencing the degree of coupled coordination of the two systems. The eastern region should accelerate the optimization of industrial structure, enrich the stock of human capital, improve the quality of human capital, create a world-class digital industry base and talent training platform, and lead the coupled and coordinated development of the two systems. The central region should expand the development scale of towns and cities, improve the quality of human capital, actively undertake new industrial professions, optimize the industrial structure, strengthen the government's regulatory role in the coupled and coordinated development of the two systems, and further improve infrastructure construction. The western region should accelerate the construction of new urbanization, focus on the introduction of talents, actively develop advantageous industries, and give full play to the macro-control role of the government's "visible hand".

Conflict of Interest

The authors declare no conflict of interest.

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