

Research on the Coupling and Coordination of Green Finance and Green Innovation Efficiency in Beijing-Tianjin-Hebei Region

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Abstract: This study employs a comprehensive approach integrating CRITIC-grease correlation, SBM-DEA model, coupling coordination model, and Tobit model to analyze the dynamic characteristics and underlying drivers of coupling coordination between green finance and green innovation efficiency in the Beijing-Tianjin-Hebei region from 2014 to 2023. The findings reveal a steady upward trend in the region's green finance and green innovation efficiency, laying a solid foundation for subsequent coupling coordination analysis. Further analysis demonstrates strong regional coordination with continuously improving coupling coordination levels. In terms of influencing factors, the technological and economic development level shows the most significant positive impact on coupling coordination, while human capital exhibits a certain negative influence. Therefore, the Beijing-Tianjin-Hebei region should strengthen regional cooperation, stimulate innovation vitality, and enhance government intervention to consolidate the coupling coordination system between green finance and green innovation efficiency. This will drive the development of surrounding cities and provide robust support for regional green transformation.

Keywords: Tobit Model; Coupling Coordination; CRITIC-greasing Degree; Green Finance.

1. Introduction

Driven by the "dual carbon" goals, China's green economy and innovation have achieved breakthrough progress, unleashing new momentum. Actively developing green finance and fostering its deep integration with green innovation is not only essential for implementing the "lucid waters and lush mountains are invaluable assets" philosophy and advancing ecological civilization, but also crucial for promoting green and low-carbon transformation [1]. In the Beijing-Tianjin-Hebei region, coordinated governance has become a key driver of regional green development. By combining technological breakthroughs with green industrial upgrades, this approach provides robust support for the synergistic development of green finance and innovation [2]. A close interdependence exists between green finance and innovation: On one hand, green innovation offers solid technical foundations for financial development, serving as a vital tool to balance economic growth and environmental protection. On the other hand, green finance accelerates corporate green transformation by funding innovation activities. It not only supports R&D investments and mitigates innovation risks, but also creates market-driven pressure through regulatory mechanisms [3], guiding enterprises to expedite green transitions. This forms a critical institutional safeguard for upgrading development models toward greener practices.

Scholars have extensively studied green finance and green innovation efficiency. Research consistently indicates that green finance, leveraging financial instruments such as credit, investment, insurance, and bonds, serves as a vital funding source for green technological innovation and industrial upgrading. Meanwhile, the deepening of green innovation has expanded the application scope of green finance, further stimulating innovation in financial products and services, creating a virtuous cycle. In their research on the Yellow River Basin, scholars including Li Guangqin emphasized [4] that

the synergy between the two is the core pathway to achieving high-quality regional development. Ning Chengqian [5] validated the significant coupling coordination between green finance and green innovation at the corporate level, finding that factors like technological investment significantly influence coordination levels. Zhang Xiufan [6], through provincial-level analysis, examined the coupling coordination among green finance, green innovation, and technology finance, revealing development disparities in central and western regions. Xu Lang [7], using a "macro-micro" dual-dimensional perspective in his Yangtze River Economic Belt study, identified imbalances in the coordinated development of green finance efficiency and ecological resource efficiency. Most studies analyze the distribution patterns of coupling coordination levels between green finance and green innovation in China, showing an "east-high-west-low" pattern with coastal areas significantly higher than inland regions. Li Jing [8] found in his Yellow River Basin research that downstream areas exhibit higher coupling coordination levels compared to upstream regions, highlighting regional disparities. Cai Hongchuan [9], through municipal-level analysis of Zhejiang Province, noted that despite annual improvements in overall coordination levels, regional gaps persist, indicating ongoing challenges in coordinated development.

In summary, while scholars have established theoretical and practical foundations for understanding the coupling relationship between green finance and green innovation, certain research gaps remain. As a key economic development zone in China, the Beijing-Tianjin-Hebei region requires leveraging existing achievements to conduct targeted studies, thereby providing theoretical support for regional green integration. This paper investigates the coupling coordination between green finance and green innovation efficiency in the Beijing-Tianjin-Hebei region.

2. Indicator System Construction

This study draws on the academic achievements of Gao Jinjie and Xie Jiandong [10][11], integrating the practical conditions of the Beijing-Tianjin-Hebei region. It constructs a green finance evaluation system applicable to the region through four dimensions and ten indicators: green credit, green securities, green insurance, and green investment. The green credit indicator primarily reflects the constraints imposed by high-energy-consuming industries on green finance, as well as the supply status of green funds in regional financial markets. Green securities respectively reflect the financing capabilities of six major high-energy-consuming

enterprises and energy-saving/environmental protection enterprises. Referring to the literature of scholars Ren and Xie Jiandong [10], the agricultural insurance scale proportion and claim ratio are selected as tertiary indicators under the green insurance dimension, as agricultural insurance is the most mature and representative business segment in the green insurance system [13]. Drawing on existing research by scholars Zhang Gui [13], He Xionglang [14], and Zhang Yuli [15], an evaluation index system for green innovation efficiency is constructed and measured through three dimensions: innovation input, expected output, and unintended output [16].

Table 1. Evaluation Index System

primary indicator	secondary indicator	tertiary indicator	Attribute
green finance	green-credit policy	interest expense ratio of energy intensive industry	-
		Green credit (scale) share	+
	green securities	market share of energy-intensive industries	-
		Market Value Ratio of Listed Companies in Energy Conservation and Environmental Protection	+
	green insurance	scale proportion of agricultural insurance	+
		agricultural insurance loss ratio	+
	green investment	proportion of fiscal expenditure on environmental protection industry	+
		Investment scale proportion in environmental pollution control	+
Green Innovation	Innovation investment	R&D personnel equivalent to the total (person-years) at that time	+
		internal expenditure of R&D	+
	expected output	Number of patent grants	+
		GDP	+
		gross output value of industrial enterprises above designated size	+
	unintended output	comprehensive energy consumption per unit output value	-
		Industrial wastewater discharge	-

Based on the evaluation index system described above, this study selects panel data from 2014 to 2023 covering all prefecture-level cities in the Beijing-Tianjin-Hebei region (including Beijing, Tianjin, and 13 prefecture-level cities in Hebei Province). The data are sourced from authoritative platforms such as the CSMAR database, EPS database, China Economic Net statistical repository, the National Bureau of Statistics, and the Statistical Yearbooks published by local governments in the region.

3. Research Methods

3.1. Data Standardization

The standardization formula for positive indicators is:

$$x'_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$$

The standardization formula for negative indicators is:

$$x'_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)}$$

Here, denotes the x_{ij} x_{ij} i j i -th i indicator x'_{ij} j value

x'_{ij} $\max(x_{ij})$ in the i -th j year; is the $\max(x_{ij})$ standardized $\min(x_{ij})$ j j value, where $\min(x_{ij})$ is j the maximum value of the i -th indicator and is the minimum value of the i -th indicator.

3.2. Improved CRITIC-GRAUY RELATIONSHIP

Calculate information capacity:

Calculate j j the contrast intensity of the specified metric:

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^m (x'_{ij} - \bar{x}'_j)^2}{m-1}}$$

The conflict between evaluation index system:

$$f_j = \sum_{i=1}^m (1 - r_{ij})$$

Calculate information capacity:

$$C_j = \sigma_j f_j$$

Calculate weight:

$$w_j = \frac{C_j}{\sum_{j=1}^n C_j}$$

The reference sequence is the optimal value of each indicator, and the values of each indicator are used as comparison sequences to calculate the correlation coefficient:

$$\xi_i(k) = \min_k \left(\frac{\min |x_0(k) - x_i(k)| + \rho \max |x_0(k) - x_i(k)|}{\max |x_0(k) - x_i(k)| + \rho \max |x_0(k) - x_i(k)|} \right)$$

where ρ is the resolution coefficient, with $\rho = 0.5$ smaller values indicating higher resolution capability.

Calculate relevance:

$$\gamma_i = \frac{1}{n} \sum_{k=1}^n \xi_i(k) w_j$$

This compares n the number of sequences.

3.3. SBM-DEA Model

Using MaxDEA software, the SBM-DEA model quantitatively measures green innovation efficiency in terms of inputs, expected outputs, and unintended outputs [17]. It effectively addresses issues such as input excess, output deficiency, and input-output slack, enabling a more scientific,

accurate, and comprehensive assessment of green innovation efficiency in the Beijing-Tianjin-Hebei region. This provides a solid foundation for subsequent coupling coordination models.

3.4. Coupling Coordination Degree Model

Based on the above measurement of green finance and green innovation efficiency, the coupling coordination between the two is analyzed.

Build the following model:

$$C = 2 \cdot \frac{\sqrt{U_1 \cdot U_2}}{U_1 + U_2}$$

$$T = \alpha U_1 + \beta U_2$$

$$D = \sqrt{C \cdot T}$$

In this framework, C denotes the coupling degree between green finance and green innovation efficiency, while α 、 β α 、 β T represents their comprehensive coordination index.

The $\alpha = \beta = 0.5$ weight $\alpha = \beta = 0.5$ coefficients for green finance and green innovation efficiency are respectively indicated. Based on existing research, the coupling degree C and coordination degree D are categorized into the following levels.

Table 2. Coupling Coordination Level

degree of coupling C	coupling order	coupling coordination degree D	coupling coordination level
$0 \leq C \leq 0.3$	ultra-low coupling	$0 \leq D \leq 0.2$	major maladjustment
$0.3 \leq C \leq 0.4$	low coupling	$0.2 \leq D \leq 0.4$	Moderate dysregulation
$0.4 \leq C \leq 0.5$	primary coupling	$0.4 \leq D \leq 0.5$	approaching to depletion
$0.5 \leq C \leq 0.6$	moderate coupling	$0.5 \leq D \leq 0.6$	barely coordinated
$0.6 \leq C \leq 0.7$	highly coupled	$0.6 \leq D \leq 0.8$	intermediate coordination
$0.7 \leq C \leq 1.0$	highly coupled	$0.8 \leq D \leq 1.0$	Quality Coordination

3.5. Tobit Model

The data of green finance and green innovation efficiency are bimodal with a cutoff between 0 and 1, exhibiting characteristics of truncation and stage-specificity. Therefore, this study employs the Tobit model to analyze the impact of coupling coordination factors. Given its strong capability in handling cross-sectional data, the Tobit model demonstrates high estimation precision and reliability.

The Tobit model formula is as follows:

$$D_{it} = \beta_1 J_{it} + \beta_2 R_{it} + \beta_3 Z_{it} + \beta_4 K_{it} + \beta_5 C_{it}$$

Here, D denotes the coupling coordination degree, i represents the region, t indicates the time, J signifies the economic development level, R stands for the human capital development level, Z reflects the degree of government intervention, K indicates the technological innovation level, and C denotes the industrial structure development level.

4. Empirical Results

4.1. Measurement Results of Green Finance

Using the CRITIC-GRASSY RELATIONSHIP METHOD, we measured the green finance development levels of prefecture-level cities in Beijing-Tianjin-Hebei region from 2014 to 2023. The results show that the green finance development index fluctuated between 0.66 and 0.84 over the decade without a clear upward trend. The peak value of 0.776

was recorded in 2014, while the index dropped to 0.665 in 2023, returning to pre-2014 levels. This indicates the region remains in the "initial-stage fluctuation" phase, having not yet entered a sustained growth trajectory.

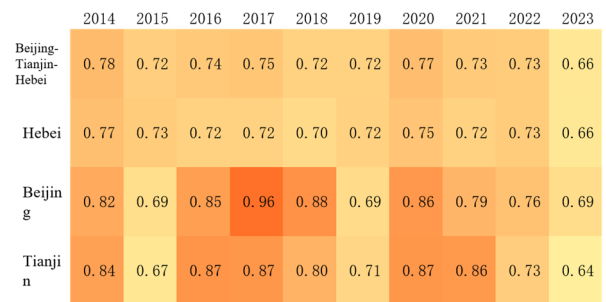


Figure 1. Heat map of green finance development level

4.2. Measurement Results of Green Innovation Efficiency

The chart reveals that Beijing's green innovation efficiency has maintained a relatively stable development level, with minor fluctuations around 1, demonstrating a solid foundation and stability in green innovation. Tianjin initially achieved high green innovation efficiency (approximately 2014-2017), but experienced a significant decline afterward. Although some recovery occurred later, the overall efficiency dropped substantially compared to earlier periods, likely due to challenges such as reduced input-output efficiency in green

innovation and industrial restructuring during development. Hebei Province's green innovation efficiency has remained at a relatively low level with minimal fluctuations over the years, indicating potential issues like insufficient investment, weak innovation capacity, and low efficiency in green technology transfer, resulting in relatively lagging green innovation development.

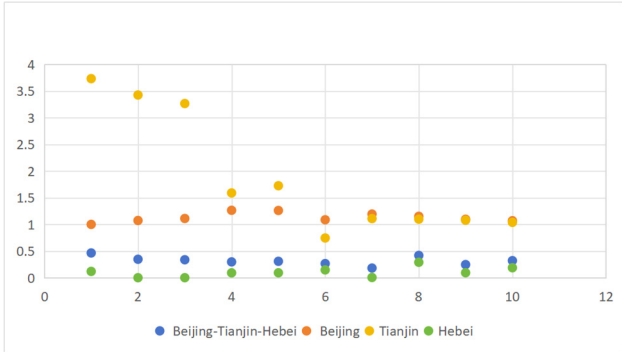


Figure 2. Trend chart of green innovation efficiency development level

Overall, the green innovation efficiency in the Beijing-Tianjin-Hebei region remains low. The uneven development of green innovation across provinces and cities (e.g., Tianjin's high efficiency in the early stage followed by decline, and Hebei's long-term low efficiency) has slowed progress in overall green innovation efficiency. The role of regional collaboration in driving efficient green innovation development still needs further enhancement.

4.3. Coupling and Coordination Analysis

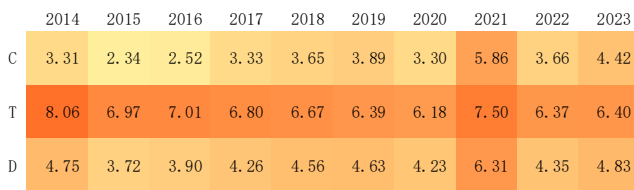


Figure 3. Coupling Coordination Heat Map

The chart reveals that the coupling coordination degree (D) of green finance and green innovation efficiency in the Beijing-Tianjin-Hebei urban agglomeration exhibits two distinct phases. The first phase (2014-2021) marked a low coordination stage. During this period, local governments in the region submitted work reports to President Xi Jinping, elevating the Beijing-Tianjin-Hebei area to a national strategic level. However, coordination remained inadequate due to the region's heavy reliance on industrial structure adjustment and transformation pressures. The lack of effective incentive mechanisms and risk management tools hindered corporate innovation, while uneven resource distribution—particularly Beijing's concentration of technological innovation capabilities—further impeded regional coordination. The second phase (2021-2023) saw the region enter a barely coordinated stage. Under the guidance of the 20th National Congress of the Communist Party of China and the implementation of directives from the National Financial Regulatory Administration, local governments jointly issued policy documents to promote industrial transformation and green transition, driving coordinated development between green finance and green innovation efficiency.

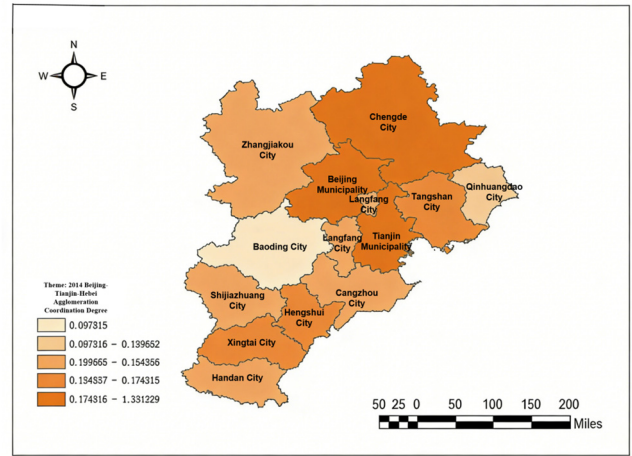


Figure 4. Coupling Coordination Degree of Beijing-Tianjin-Hebei Region in 2014

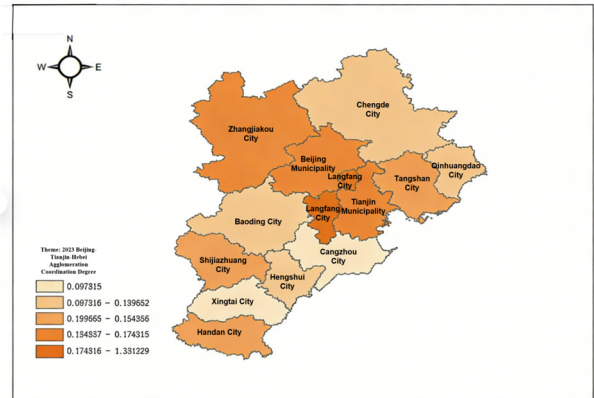


Figure 5. Coupling Coordination Degree of Beijing-Tianjin-Hebei Region in 2023

4.4. Results of Tobit Model Analysis

Table 3. Tobit Model Results

variable	regression coefficient	standard error	t price	P price
level of economic development	0.3072	0.0794	3.87	0.000
human capital	-0.3302	1.6496	-0.20	0.842
government intervention	1.9809	0.4354	4.55	0.000
technological innovation	4.5769	3.4147	1.34	0.183
industrial structure	0.6768	0.3572	1.89	0.060
constant term	-3.8791	0.8540	-4.54	0.000

The analysis reveals that economic development level, government intervention, technological innovation, and industrial structure positively influence the coupling coordination degree between green finance and green innovation efficiency, with the intensity of positive effects ranked as technological innovation > government intervention > industrial structure > economic development level. Human capital, however, has a negative impact. This indicates that technological intensity serves as the primary positive driver for the coupling coordination between green finance and green innovation in the Beijing-Tianjin-Hebei region, while human capital acts as the main negative factor hindering their coordinated development.

5. Conclusion and Recommendations

5.1. Conclusion

This study utilizes municipal panel data from 14

prefecture-level cities in the Beijing-Tianjin-Hebei urban agglomeration (2014-2023) to construct a comprehensive evaluation index system for the coupling coordination between green finance and green innovation efficiency. Based on this framework, the CRITIC-greasy correlation coefficient and SBM-DEA models were employed to measure the development levels of green finance and green innovation efficiency respectively, followed by an analysis of their developmental changes. Building upon this foundation, a coupling coordination model was applied to examine the interrelationship between green finance and green innovation efficiency in the Beijing-Tianjin-Hebei region. Subsequently, the Tobit model was utilized to analyze the factors influencing this coupling coordination relationship. The key findings are summarized as follows:

1) The development of green finance and green innovation efficiency in the Beijing-Tianjin-Hebei region has stabilized overall, showing a steady growth trend that lays the groundwork for subsequent coupling and coordination analysis. Over time, the region's green finance development has remained relatively stable with minor fluctuations. Beijing and Tianjin achieved relatively high levels of green finance development in 2017 and 2018, respectively, reflecting the significant impact of coordinated development measures. Both the regional and individual levels of green innovation efficiency have shown an upward trend, with Tianjin demonstrating the most substantial growth. While other regions maintained stable and rising trends, the overall development of green finance and green innovation efficiency in the Beijing-Tianjin-Hebei region still requires improvement, necessitating further intervention measures.

2) The coupling coordination analysis reveals that the Beijing-Tianjin-Hebei urban agglomeration demonstrates relatively strong synergy between green finance and green innovation efficiency, with the coupling coordination degree maintaining stability and showing an upward trend. Although fluctuations occurred during 2014-2023, the overall development of green finance and green innovation efficiency in this region remained stable. Notably, while the coordination level was initially excellent, recent years have seen some setbacks in the development of coupling coordination, indicating that the synergy between green finance and green innovation efficiency has not reached optimal levels and faces certain developmental bottlenecks.

3) Influencing factors, the coupling coordination of green finance and green innovation efficiency in Beijing-Tianjin-Hebei region is affected by some factors: scientific and technological innovation, government intervention, industrial structure, economic development level, human capital. Among them, the effect of scientific and technological innovation is the highest in the positive influencing factors, and human capital is the negative influencing factor.

5.2. Recommendations

1) Enhance regional coordination and optimize resource allocation efficiency. Further deepen the cooperation mechanism among Beijing, Tianjin, and Hebei by establishing a cross-regional information sharing platform. Remove regional barriers to the circulation of financial instruments such as green credit and green securities, facilitating the integration of Beijing's technological resources, Tianjin's industrial foundation, and Hebei's cost advantages in production factors. Establish a regional green innovation coordination fund to focus on cross-provincial

green technology R&D and commercialization, helping to narrow the development gap among the three regions. Simultaneously, unify regional green finance standards and environmental information disclosure requirements to avoid resource misallocation caused by policy fragmentation, thereby forming a virtuous cycle of "policy coordination—resource aggregation—efficiency improvement."

2) Focus on core drivers to enhance synergistic coordination. Prioritize technological innovation as the primary lever, increasing funding and policy support for green technology R&D. Target breakthroughs in key technological bottlenecks across energy conservation, environmental protection, and clean energy sectors, while expanding green finance applications through technological iteration. Strengthen government guidance by optimizing fiscal fund allocation, boosting public spending on environmental protection and pollution control investments, refining green finance incentive policies, and directing financial institutions and private capital toward green sectors.

3) Overcoming human capital constraints and strengthening talent support systems. To counteract the negative impact of human capital on coordinated development, a specialized mechanism for cultivating and allocating green professionals should be established. Universities and vocational institutions may introduce majors in green finance and green innovation, training interdisciplinary talents with expertise in financial knowledge, environmental technology, and regional collaboration. A cross-regional green talent mobility market should be created, utilizing policy subsidies and optimized career development pathways to attract high-caliber professionals to underdeveloped green innovation regions like Hebei. This initiative will address talent shortages and misallocation, providing human capital support for the deep integration of green finance and green innovation.

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