A Study on the Construction and Policy Optimization of a Symbiotic System for Provincial-Level Digital Finance and Green Innovation in the Context of the "Dual Carbon" Goals

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Abstract: In this paper, we discuss how to coordinate the development of digital finance and green innovation in the context of "Dual Carbon" objectives. Using the entropy weighting method, it examines the co-evolution characteristics of the two systems. Results show digital finance is scale-driven, while green innovation exhibits input – output mismatch. Although coupling coordination improves, it remains at medium – low levels. Technological innovation and green finance variables have significant impact on the coordination, and this paper puts forward a structural adjustment based on the optimization of factors.

Keywords: Digital finance; Green innovation; Coupling coordination; Entropy weighting method; Dual carbon goals

1. Introduction

Constrained by the "Dual Carbon" goal, the province's economy is facing a need for green transformation and financial restructuring. The allocation of resources and the transfer of information is increasingly shaped by digital funding, but structural differences in environmental innovation remain [1]. Centered on "foundation – scale – potential" and "input – output – environment" systems, a unified measurement framework and coupling model are constructed to characterize the evolution and interaction, identify coordination phases, and provide quantitative support for structural adjustment and policy path.

2. Indicator System and Measurement Methods

2.1 Digital Finance Indicator System and Weight Analysis

The Digital Finance Framework is structured into fundamentals, size, and potential. The fundamentals capture infrastructure and industry support; the size reflects the volume of transactions and the penetration of services; the potential represents the technical capability and the integration of green finance. Key indicators are fintech patents, digital loans, and green finance instruments. The weights are given in Table 1.

Table 1. Digital Finance Weightings

Primary Indicators	Core Indicator	Weight
Digital Development Foundation	Number of Mobile Internet Users	0.0507
	Third-party payment transaction volume	0.1051
	Number of Fintech Companies	0.1514
Scale of digital development	Online payment transaction volume	0.1236
	P2P online lending transaction volume	0.0748
Digital Development Potential	Number of Fintech patent applications	0.0993
	Green Credit Balance	0.0646

2.2 Construction of the Green Innovation Indicator System

Based on the input – output – environment framework, inputs include R&D staff ratio, expenditure intensity, capital stock, and inverse energy intensity. Outputs include green patents, new product sales, productivity, and pollution indicators. The environmental dimension is based on GDP per person, education expenditure, R&D enterprise share, and pollution control investment.

2.3 Entropy Measurement Method

(1) Data Standardization

To address indicators with different units of measurement, the raw data x_{ij} is standardized. Forward indicators use

$$z_{ij} = \frac{x_{ij} - \overline{x}_j}{s_j} \quad (1)$$

For negative indicators,

$$z_{ij} = \frac{\overline{x}_j - x_{ij}}{s_j} \quad (2)$$

where $\overline{x}_j$ and s_j represent the mean and standard deviation of the j th indicator, respectively. To avoid invalid values in logarithmic calculations, the standardized results are shifted as follows:

$$z'_{ij} = z_{ij} + A \quad (3)$$

(2) Calculation of Indicator Entropy

Calculate the proportion of the i th sample under the j th indicator:

$$p_{ij} = \frac{z'_{ij}}{\sum_{i=1}^{n} z'_{ij}} \quad (4)$$

Calculate the information entropy based on this:

$$e_j = -k \sum_{i=1}^{n} p_{ij} \ln p_{ij} \quad (5)$$

where $k = 1/\ln n$.

(3) Determination of Weights

Calculate the coefficient of variation:

$$d_j = 1 - e_j \quad (6)$$

This yields the indicator weights:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \quad (7)$$

2.4 Symbiotic Mechanisms and Coupling Model Construction

The symbiosis is a two-way path by means of factors allocation, technology diffusion, and environment restriction: Digital finance affects the input and output of green innovation, and then returns to finance structure. Based on the interactive characteristics of the two systems, a coupling degree model is constructed to characterize the intensity of the synergistic relationship:

$$C = \frac{2\sqrt{F \times G}}{F + G} \quad (8)$$

Here, C represents the coupling degree, F represents the comprehensive index of digital finance, and G represents the comprehensive index of green innovation. The coupling degree ranges from $0 \le C \le 1$, with its value determined by the relative consistency and degree of synergy in the development levels of the two systems.

3. Empirical Analysis and Policy Pathways

3.1 Analysis of Development Characteristics

On the basis of the entropy weighting method, a time-series comparison of the Digital Finance Index and the Green Innovation Index (DI) for the period 2015 – 2023.as illustrated in Figure 1 is a steady increase, with an acceleration of growth from 2018, mainly due to the proliferation of online payments and the clustering of fintech. The Green Innovation Index is generally better, but it is fluctuating, with input growth outpacing output transformation. The evolution of the two indices reveals a phase difference: digital finance is the first to expand, and the green is the second to react. From a structural point of view, the scale index makes a significant contribution, while the output and ecosystem improvements are lagging behind, suggesting an asynchronous rhythm of development.

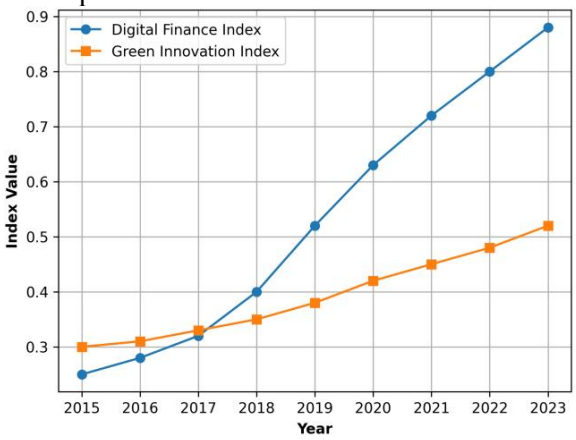

Figure 1. Trend Line Chart

3.2 Analysis of Coupling Coordination

As illustrated in Figure 2, the coupling degree shows a general upward trend, moving from low to middle to high, with fluctuations indicative of instability between systems. The improvement is mainly due to the stronger linkages between the STI indicators and the eco-innovation potential. As illustrated in Figure 3, the majority of regions are still in the primary or intermediate level of coordination, with the significant contribution of green credit and fintech patents, while the impact of pure scale expansion is limited.

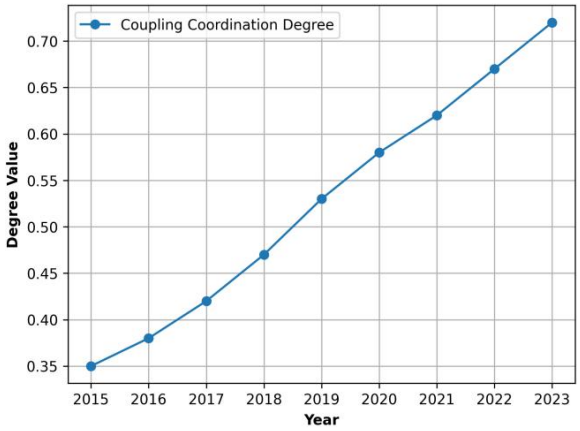

Figure 2. Curve of Changes in Coupling Coordination

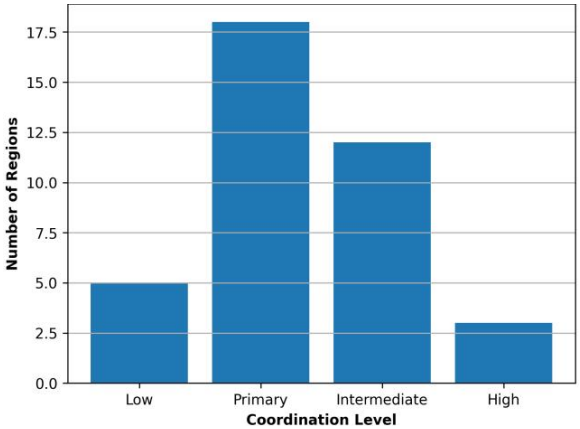

Figure 3. Bar Chart of Coordination Level Distribution

3.3 Policy Optimization Pathways

Based on the structural features of DFI and GI, we develop policy paths in three dimensions: factor allocation, structural adjustment, and institutional constraints [2]. As far as factor allocation is concerned, efforts should be made to enhance the targeted allocation of funds towards green innovation, to increase the accuracy of the delivery of green loans and the accuracy of digital identification, and to ensure that R&D investments are in line with green projects.Regarding the structural adjustment, optimizing the development structure of digital finance so as to reduce the role of transaction volume, enhance the integration of fintech and green scenarios, and facilitate the use of blockchain and AI in project assessment and risk identification [3]. As far as institutional constraints are concerned, there is a need to improve the coordination mechanism between environment legislation and financial regulation, and to adjust dynamically the intensity of pollution control investments and environmental financing instruments in order to limit the spread of funding to energy intensive projects.

4. Conclusion

At the provincial level, the development of digital finance and green innovation has changed from asymmetrical to coupled, and the interaction between scale expansion, technology innovation and green orientation has restricted coordination. On the basis of measurement and coupling analysis, the integration of multidimensional data and the optimization of dynamic models can enhance the comparison and time identification of regions, enhance the quantification of GDI, and improve the alignment of policy tools and systems.

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