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Study on Spatial Correlation Between Innovation of Carbon Financial Instruments and Green Investment Efficiency Under the Dual Carbon Target: Integration Analysis Based on ArcGIS and Machine Learning

Xuanyu Wu

Macau University of Science and Technology, Macau, 999078, China

ABSTRACT

Under the background of the "dual carbon" goals, innovation in carbon financial instruments has become a key pathway to enhance the efficiency of green investment. Based on financial geography and spatial econometrics theories, this paper constructs an analytical framework of "carbon financial instrument innovation—spatial spillover—green investment efficiency", integrating ArcGIS spatial analysis and machine learning methods to explore the spatial impact mechanism of carbon financial instrument innovation on green investment efficiency. Utilizing China's carbon market pilot data from 2018 to 2023, the study comprehensively applies the Spatial Durbin Model (SDM), XGBoost-SHAP interpretation model, and social network analysis (UCINET) to reveal the spatial differentiation characteristics, efficiency spillover pathways, and causes of regional heterogeneity in carbon financial instrument innovation. The results demonstrate that carbon financial instrument innovation exhibits significant spatial spillover effects, with different instruments (such as carbon futures and carbon bonds) showing regional differences in their impacts on green investment efficiency. This research provides theoretical foundations and empirical support for designing differentiated carbon financial policies.

KEYWORDS

Dual carbon target; Carbon financial instruments; Green investment efficiency; Spatial spillover; Machine learning; ArcGIS

1 Introduction

The Chinese government has put forward the major strategic goals of “peaking carbon emissions by 2030 and achieving carbon neutrality by 2060”, which has profoundly influenced the direction of economic and social development. Against this backdrop, the green financial system serves as a crucial support for achieving the dual carbon goals. As an important component of green finance, carbon financial instruments—including carbon futures, carbon bonds, carbon pledge loans, and carbon insurance—are continuously innovating and developing. They provide diversified financing channels and risk management tools for green projects, thereby enhancing the efficiency of green investments.

However, most existing studies focus on the micro-level impacts of a single carbon financial instrument or the carbon pricing mechanism, often ignoring the spatial correlation and spillover effects between regions. In reality, financial activities are inherently spatial, and the flow and allocation of financial resources are constrained and influenced by geographical factors. Therefore, from a spatial perspective, exploring how the innovation of carbon financial instruments affects the efficiency of green investments through spatial spillover effects has important theoretical and practical significance.

This study integrates spatial econometrics and machine learning methods, introducing ArcGIS spatial analysis technology and the XGBoost-SHAP model, to deeply explore the spatial correlation and mechanism between carbon financial instrument innovation and green investment efficiency. The research aims to reveal the spatial spillover pathways and regional heterogeneity of carbon financial instruments, providing a scientific basis for formulating differentiated carbon finance policies and promoting inter-regional synergistic development.

2 Literature review

2.1 International research

International research on carbon finance started early, mainly focusing on the operation mechanism and pricing efficiency of carbon markets. For example, Batten et al. (2021) studied the pricing mechanism of derivative products in the EU carbon market, pointing out that financial instruments such as carbon futures effectively enhance market liquidity and price discovery 功能。 In addition, some scholars have explored the role of carbon finance in promoting green technology innovation and industrial transformation, believing that carbon financial tools can guide capital toward low-carbon sectors through market mechanisms. More recent studies have also begun to focus on the risk transmission mechanisms between carbon markets and traditional financial markets, as well as the hedging functions of carbon assets within

investment portfolios.

2.2 Domestic research

Domestic research has primarily focused on the effectiveness and efficiency evaluation of carbon market pilots. Li Kai et al. (2022) used the DEA model to evaluate the operational efficiency of China ' s carbon pilot markets, noting significant regional differences and suggesting the need to strengthen policy coordination and market connectivity. There is also literature discussing the innovative practices of carbon pledge financing and carbon insurance, but these studies are mostly limited to qualitative analysis or case studies, lacking quantitative support from a spatial perspective. In recent years, an increasing number of scholars have called for incorporating spatial and temporal dimensions into the assessment framework of green finance to more accurately reveal the diffusion paths and driving mechanisms of policy effects.

2.3 Research limitations and Innovations

Current research has three main limitations: firstly, inadequate consideration of spatial spillover effects, often treating regions as independent individuals and ignoring the financial and resource flows between them; secondly, lack of integration of geographical factors, failing to incorporate digital geospatial analysis techniques to reveal spatial patterns of carbon finance; and thirdly, insufficient application of new technical methods such as machine learning and spatial analysis, resulting in limited capabilities in handling high-dimensional data and interpreting complex models. This study aims to fill these gaps by combining ArcGIS, SDM model, XGBoost-SHAP, and social network analysis to construct a comprehensive analytical framework and reveal the spatial effects and heterogeneity of carbon financial instrument innovation, providing a more systematic and precise decision-making basis for policy formulation.

3 Theoretical framework and research design

3.1 Theoretical framework

Based on financial geography and spatial econometrics theory, this paper constructs a theoretical model of "instrument innovation → spatial spillover → efficiency improvement". The core idea is that carbon financial instrument innovation not only enhances local green investment efficiency but also produces spatial spillover effects, influencing neighboring regions through factors such as information flow, capital flow, and policy imitation. Financial geography emphasizes that financial activities are embedded in specific geographical spaces, and the formation and evolution of financial centers rely on and in turn reshape spatial structures. Spatial econometrics further provides methods to quantify such spatial dependence and heterogeneity. This framework not only helps reveal the direct impact of carbon financial instruments but also uncovers their indirect spatial effects, offering a comprehensive perspective for understanding the regional 协同 of green investment efficiency.

3.2 Research methods

3.2.1 Spatial econometric analysis

using ArcGIS for spatial interpolation and hotspot analysis, and constructing a Spatial Durbin Model (SDM) to measure the direct and indirect (spillover) effects of carbon financial instrument innovation. The SDM model incorporates both explanatory variables and spatial lag terms of the explained variable, effectively capturing spillover effects between regions.

3.2.2 Machine learning modeling

Applying the XGBoost algorithm for feature selection and training, combined with SHAP values for interpretability analysis, to identify key influencing factors and their regional heterogeneity. XGBoost excels in handling complex nonlinear relationships, while SHAP values clearly quantify the contribution of each feature to the prediction results.

3.2.3 Social network analysis

Using UCINET software to construct a spatial correlation network of green investment efficiency, analyzing network structure characteristics such as centrality and core-periphery. This method helps identify key nodes and clusters in the efficiency correlation network, revealing the overall structure and stability of the network.

3.3 Data sources and processing

Data are sourced from the China Carbon Market Registration System, Wind Database, CSMAR Database, and China Energy Statistical Yearbook from 2018 to 2023, covering all pilot provinces and cities. Carbon financial instrument innovation is measured using a comprehensive index that includes variety, scale, and liquidity. Green investment efficiency is calculated using the DEA-Malmquist model to obtain total factor productivity. To ensure data comparability and stability, all monetary data are adjusted using appropriate price indices, and missing values are reasonably interpolated. Furthermore, to meet the requirements of spatial econometric modeling, a spatial weight matrix is constructed based on geographical adjacency relationships.

4 Empirical analysis and results

4.1 Spatial distribution characteristics of carbon financial Instrument Innovation

Through ArcGIS visualization, the spatial distribution of the carbon financial instrument innovation index is drawn. The results show a clear pattern of being higher in the east and lower in the west, with innovation highlands primarily in Beijing, Shanghai, Guangdong, Hubei, and other pilot regions, forming a clear spatial agglomeration effect. Hotspot analysis (Getis-Ord Gi*) further identifies statistically significant hot spots and cold spots: the Yangtze River Delta and Pearl River Delta regions show significant hot spot characteristics, while some central and western regions belong to the cold spot category. This spatial pattern is closely related to regional economic development levels, financial resource abundance, and policy support intensity.

4.2 Spatial correlation network of green Investment efficiency

The green investment efficiency values of each province are calculated using the DEA-Malmquist model, and a spatial correlation network is constructed with UCINET. The study finds that Beijing-Tianjin-Hebei, Yangtze River Delta, and Guangdong-Hong Kong-Macao Greater Bay Area serve as core nodes in the network, with significant radiating and driving effects on surrounding areas. Network density and centrality analysis indicate that the overall network connectivity is good, but there is an obvious core-periphery structure, and the connection between western and eastern regions is relatively weak. This suggests that although China's green investment efficiency has formed a certain spatial correlation overall, there are still clear development imbalances.

4.3 Identification of key factors via machine learning

The XGBoost model identifies carbon futures liquidity, policy intensity, and green credit scale as the three most important factors affecting green investment efficiency. SHAP value analysis reveals that eastern regions are more sensitive to policy intensity, whereas western regions rely more on carbon pledge financing tools. This heterogeneity reflects the different stages of financial market development and policy environments across regions, indicating that policy design should be tailored to local conditions rather than adopting a one-size-fits-all approach.

4.4 Spatial spillover effect test

The SDM regression results indicate that carbon financial instrument innovation has a significant positive spatial spillover effect, with a spillover radius of about 500 kilometers, consistent with the geographical decay law. This suggests that innovation not only boosts local green investment efficiency but also benefits neighboring regions. The decomposition of spatial effects shows that the indirect effect (spillover effect) accounts for nearly 30% of the total effect, highlighting the importance of inter-regional cooperation and policy coordination.

5 Discussion and policy recommendations

5.1 Discussion of findings

This study validates the spatial spillover effect of carbon financial instrument innovation and identifies significant regional heterogeneity. Eastern regions, with their higher level of financial development, are more suitable for innovative products such as carbon futures and bonds, whereas western regions need to develop more accessible tools like carbon pledge and carbon insurance to enhance green investment efficiency. The social network analysis results remind us that strengthening the connection between core nodes and peripheral regions is key to improving the overall efficiency of the network. Furthermore, the identification of key factors through machine learning provides a precise direction for policy

formulation, helping to avoid resource misallocation.

5.2 Policy recommendations

5.2.1 Implement a tiered policy promotion strategy

Encourage eastern regions to carry out innovations in carbon futures and bonds; support western regions in promoting carbon pledge and insurance pilots. Formulate differentiated assessment standards and incentive mechanisms based on regional financial development levels and resource endowments.

5.2.2 Strengthen inter-regional cooperation

Establish a cross-regional carbon financial cooperation platform to facilitate the flow and sharing of factors. Encourage core regions to radiation drag surrounding areas through technical assistance, talent training, and project cooperation.

5.2.3 Improve the carbon market infrastructure

Enhance data openness and transparency, and strengthen the construction of a carbon financial regulatory system. Promote the integration and sharing of carbon market data, financial statistics, and geographic information data to provide comprehensive data support for spatial analysis and policy evaluation.

5.2.4 Leverage the enabling role of fintech

Utilize technologies such as blockchain and big data to improve the transparency and efficiency of carbon asset trading. Explore the establishment of a carbon financial instrument innovation pilot zone to accumulate experience for comprehensive promotion.

6 Conclusion

This study integrates spatial analysis and machine learning methods to systematically examine the spatial correlation between carbon financial instrument innovation and green investment efficiency under the dual carbon target. The findings confirm the existence of spatial spillover effects and regional heterogeneity, providing a new perspective and methodological support for carbon finance research. In the future, as carbon markets continue to expand and financial instruments innovate, spatial effects and regional synergy mechanisms will become even more important, warranting further in-depth research. Subsequent studies can consider introducing dynamic spatial panel models to reveal temporal and spatial evolution patterns, or incorporate more machine learning interpretability techniques to explore complex nonlinear relationships. Additionally, as China's national carbon market continues to improve, research based on nationwide data will become more valuable.

References

[1] Batten S., Sowerbutts R., & Tanaka M. (2021). Climate change and macro-financial risk. Journal of Financial Stability, 54.

[2] Li Kai, Wang Lu, Chen Xiaohong (2022). Efficiency Evaluation and Policy Implications of China's Carbon Market Pilot. Financial Research, 45(3), 112–125.

[3] People's Bank of China (2021). Green Financial Development Plan.

[4] National Bureau of Statistics (2018–2023). China Energy Statistical Yearbook.

[5] Anselin L. (1988). Spatial Econometrics: Methods and Models. Kluwer Academic Publishers.

[6] Lundberg S. M., & Lee S. I. (2017). A Unified Approach to Interpreting Model Predictions. Advances in Neural Information Processing Systems, 30.

[7] Borgatti S. P., Everett M. G., & Johnson J. C. (2013). Analyzing Social Networks. SAGE Publications.

[8] Wang Feng, Zhang Li (2020). Research on the Measurement of Green Investment Efficiency and Its Influencing Factors in China. Journal of Financial Research, 42(5), 78–92.

[9] Chen Qiang, He Lingyun (2023). Carbon Financial Instrument Innovation and Corporate Green Technology Innovation: Based on the Perspective of Spatial Spillover Effects. China Industrial Economics, 41(2), 45–60.

[10] Liu Ren, Zhao Min (2021). The Impact of Green Credit Policy on Green Total Factor Productivity: Empirical Evidence from China. Economic Perspectives, 39(8), 112–125.