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# A Study of Spatial Spillovers from Fiscal Decentralization on the Efficiency of Green Economy—And the Moderating Role of Financial Decentralization

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**Abstract:** A robust fiscal and financial system constitutes a fundamental pillar of national governance. This paper investigates the spatial correlation between fiscal decentralization, financial decentralization, and local green economic efficiency using panel data from 285 cities in China. The findings reveal several key insights. First, fiscal decentralization hampers local green economic efficiency enhancement but exerts a "warning effect" on neighboring regions. In contrast, financial decentralization promotes local green economic efficiency and triggers a "clustering effect" on neighboring areas, indicating an agglomeration impact. Second, synergies from financial decentralization on local green economic efficiency are not immediately apparent, while they mitigate the enhancement of neighboring regions' green economic efficiency. Third, the maturity of the financial market system and the completeness of infrastructure positively influence the impact of financial decentralization on green economic efficiency. Fourth, fiscal and financial decentralization significantly impacts green economic efficiency in the short term, yet their long-term effects are negligible. Consequently, this paper recommends enhancing infrastructure development and instituting a dynamic mechanism for adjusting fiscal and financial decentralization. Based on the aforementioned findings, this paper provides corresponding countermeasure recommendations. These recommendations not only contribute academically to the study of green efficiency from the perspectives of fiscal and financial decentralization but also offer a Chinese model for other developing countries seeking to balance fiscal, financial, and green sustainable development.

**Keywords:** fiscal decentralization; financial decentralization; green economy efficiency; spatial spillovers; dynamic adjustment mechanisms



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## 1. Introduction

As the global economy continues to expand, the human living environment faces increasingly severe damage. PM2.5 refers to particulate matter with an aerodynamic equivalent diameter of 2.5 microns or less in ambient air. Compared to coarse atmospheric particles, PM2.5 particles are smaller, have a larger surface area, and exhibit high reactivity. They often contain toxic substances such as heavy metals and microorganisms, leading to prolonged atmospheric residence times and significant impacts on human health and atmospheric quality [1]. This increase in severe air pollution not only diminishes productivity but also reduces average life expectancy [2–5]. According to the World Health Organisation, 4.3 million people die each year due to inhalation of fine particles from indoor and outdoor air pollution. Consequently, there has been a widespread global call for sustainable economic development, which now emphasizes factors beyond mere GDP growth, such as environmental protection and resource efficiency. In this context, green economic efficiency integrates environmental considerations into the traditional evaluation of economic performance, accounting for pollutant emissions and other undesirable outputs alongside economic growth and environmental protection [6,7]. The concept of green economic efficiency encompasses economic efficiency while considering economic growth, resource consumption, and environmental pollution. It evaluates economic efficiency not only based on traditional factors like labor, capital, energy, and GDP but also incorporates environmental pollution, providing a more comprehensive measure of economic efficiency [8,9]. It serves as a crucial indicator of current economic sustainability.

The existing literature attributes ecological issues to inadequate implementation of governmental environmental policies or shortcomings in primary responsibility for environmental governance, ultimately pointing to institutional factors as central [10,11]. Fiscal decentralization entails granting local governments autonomy in debt arrangements, tax management, and budget execution by the central government [12]. Fiscal decentralization emerges as a significant institutional factor influencing the alignment of local government public policies with environmental protection goals. Over recent years, numerous countries have adopted fiscal decentralization measures, ranging from delegating spending authority to local governments to granting them tax autonomy [13,14]. This paper thus focuses on exploring the impact of fiscal decentralization on sustainable economic development, with a specific emphasis on China.

Moreover, the study incorporates China's distinctive financial and fiscal decentralization characteristics into a unified framework to comprehensively examine their effects on green economic development. Financial decentralization refers to the distribution of authority between central and local governments in financial supervision, stability, allocation of financial resources, and governance of financial entities [15,16]. Specifically, it employs a spatial correlation model to empirically analyze how fiscal decentralization and financial decentralization influence green economic efficiency using data from Chinese prefecture-level cities and above spanning 2004 to 2019. The key findings are as follows: (1) Fiscal decentralization significantly inhibits local green economic efficiency while stimulating improvements in neighboring regions. Financial decentralization, on the other hand, positively impacts green economic efficiency both locally and in neighboring areas. (2) The synergy between fiscal and financial decentralization boosts local green economic efficiency but dampens improvements in neighboring regions. (3) The impact of fiscal and financial decentralization on green economic efficiency varies across time, regions, population density, and infrastructure development. (4) Dynamic spatial analysis reveals significant short-term impacts of fiscal and financial decentralization on green economic efficiency, with less pronounced long-term effects.

This study's contributions include enriching the literature on decentralized systems and green development, particularly by integrating financial decentralization and addressing the shortcomings of previous research. By optimizing economic efficiency indicators and utilizing alternative metrics like lighting data instead of GDP to measure desired outputs, the study provides more accurate insights into green economic efficiency. These findings hold significant implications for enhancing the efficiency of the green economy in other developing countries.

The remainder of the paper is structured as follows: Section 2 reviews relevant literature, Section 3 elucidates the mechanisms through which fiscal and financial decentralization influence green economic efficiency, Section 4 details the data and main variables used, Section 5 presents empirical results, Section 6 conducts robustness tests, Section 7 explores further analysis, and Section 8 offers discussion and concludes with recommendations.

## 2. Literature Review

To systematically explore green economic efficiency under financial decentralization, this study reviews existing research in this domain and addresses its current gaps. Existing studies have not yet reached a consistent conclusion regarding the relationship between fiscal decentralization and the green economy. On one hand, regions with higher levels of fiscal decentralization receive substantial support from the central government, boosting officials' confidence in promoting green initiatives. A conducive environment enhances local government efforts in green economic growth through increased R&D investment and improved infrastructure [17,18]. On the other hand, fiscal decentralization can intensify local government competition and market segmentation. Competition manifests as either "bottom-by-bottom" or "top-by-top" competition in environmental governance, currently dominated by "bottom-by-bottom" competition. Market segmentation leads to resource mismatches, slower technological progress, and impedes eco-efficiency [19–21].

The coexistence of fiscal and financial decentralization is rarely addressed comprehensively. It can be categorized into three main frameworks. First, in macroeconomic studies, scholars argue that simultaneous decentralization may spur excessive inter-governmental competition, heightening financial risks that lead to economic volatility and hinder growth [22–25]. Second, the research explores the link between fiscal and financial decentralization and local government debt, finding that their interaction contributes significantly to debt levels, regardless of whether fiscal decentralization is measured by fiscal freedom or tax sharing [26–28]. Third, studies analyze how fiscal decentralization influences financial decentralization, with regions boasting higher fiscal revenues or expenditures wielding greater influence over local financial institutions' operations and market shares. Fiscal decentralization notably impacts financial decentralization through game-theoretic models, revealing local governments' pursuit of financial power despite associated risks from credit expansion [29].

Despite these insights, the existing literature exhibits several shortcomings. Firstly, it often equates fiscal decentralization with economic decentralization, overlooking financial decentralization. Secondly, research on factors influencing green economy efficiency predominantly focuses on foreign trade, environmental regulations, and economic structure, neglecting synergies between fiscal and financial decentralization. Lastly, fiscal decentralization and financial decentralization are closely intertwined and can be synergistic. However, scholars argue that ensuring consistency between the degree of financial decentralization and its changes is crucial, as mismatches may lead to conflicts that affect financial risks and economic development quality. It is important to note that fiscal and financial decentralization are not synonymous; regions may exhibit varying degrees of synergy or lack thereof, a nuance often overlooked in the existing literature.

This study addresses these gaps by integrating fiscal and financial decentralization within a unified framework tailored to China's decentralized system. It also considers the spillover effects of "non-expected outputs" generated during economic development in neighboring regions. Such an approach aims not only to inform improvements in China's decentralized system but also to guide the development of institutions and policies conducive to accelerating the growth of China's green economy.

## 3. Theoretical Analysis and Assumptions

Research on China's economic ascent in the realms of finance and monetary policy has undergone cycles of centralization and decentralization [30]. Presently, numerous regions exhibit a dichotomy: some are tightly controlled while others experience disorder, prompting questions about the necessity and methodology of decentralization. These issues merit extensive scholarly investigation. While scholars have predominantly focused on financial decentralization, there has been comparatively less attention given to its synergy with other aspects. Building on this observation, this paper initiates its research [31,32].

The degree of fiscal decentralization signifies the extent of local government autonomy in financial expenditures. Within the framework of devolution under Chinese characteristics, where promotion quotas are limited and competition among officials from neighboring regions is prevalent, governments often engage in a "GDP race" to secure these quotas [33]. This dynamic compels local governments to adopt the role of entrepreneurs in implementing local decisions. Consequently, local governments may reduce barriers to attract polluting industries, leading to an "environmental race to the bottom" [34,35]. Moreover, fiscal decentralization empowers local governments, potentially influencing environmental governance expenditures. Some argue that local governments may prioritize economic development over environmental protection [36–38]. Conversely, scholars suggest that as the central government emphasizes environmental governance, it channels its environmental rationality to local governments through financial transfers [39,40]. This approach encourages local governments to enhance environmental quality by attracting high-quality foreign investments, investing in human capital, and improving infrastructure [41,42]. Building on these perspectives, this paper proposes Hypothesis 1.

**Hypothesis 1A.** *Fiscal decentralization enhances green economic efficiency.*

**Hypothesis 1B.** *Fiscal decentralization does not foster the growth of green economic efficiency.*

Under the tax-sharing system, there exists a disparity between the financial and administrative powers of local governments, resulting in local budgeted financial expenditures often falling short of developmental needs [43]. Furthermore, the independence of banks prevents direct local government control over bank credit, prompting local governments to establish local financial institutions to indirectly secure additional financial resources [44,45]. As local finance evolves, attention has shifted toward regional financial issues rather than a singular national focus [46]. Financial decentralization delineates the allocation of financial resource authority between different governmental levels and between government and market institutions [47]. Local governments' pursuit of financial resources sometimes results in non-performing debts that may transform into financial institutions' non-performing assets through capital chain relationships within the financial sector [48]. This mismatch in financial resources diminishes the risk-sharing capability for corporate innovation activities. Conversely, corporate technological innovation can positively influence China's green development [49,50]. Some scholars argue that increasing financial decentralization enhances the vitality of local financial development, thereby mitigating environmental pollution [51,52]. Consequently, this paper proposes Hypothesis 2.

**Hypothesis 2A.** *Financial decentralization is conducive to improving green economic efficiency.*

**Hypothesis 2B.** *Financial decentralization is not conducive to the improvement of green economic efficiency.*

In China, financial decentralization and fiscal decentralization are closely intertwined [53]. As local governments face a decrease in the proportion of budgetary revenue but an increase in fiscal expenditures, they often resort to developing financial institutions such as local city commercial banks [54]. This strategy essentially compensates for the limitations in their budgetary functions. Therefore, financial decentralization and fiscal decentralization are coordinated efforts that aid local governments in achieving their objectives. However, against the backdrop of economic decentralization, local governments issue numerous bonds to secure funds [55]. This mismatch between resources and financial decentralization places a substantial strain on local government finances, potentially impeding the attainment of government goals [56]. Hence, this paper proposes Hypothesis 3.

**Hypothesis 3A.** *The synergy between fiscal decentralization and financial decentralization enhances the efficiency of the green economy.*

**Hypothesis 3B.** *The synergy between fiscal decentralization and financial decentralization hinders the improvement of green economy efficiency.*

## 4. Model Construction and Variable Selection

### *4.1. Variable Construction*

#### 4.1.1. Explanatory Variables

In this paper, the core explanatory variables are fiscal decentralization (FISDE), financial decentralization (FINDE), and their interaction term (FINFIS). Currently, fiscal decentralization is predominantly measured by income and expenditure perspectives in budgetary decentralization indices. Recognizing the broader applicability of expenditure-based measurements of fiscal decentralization, this paper uses both income-based fiscal decentralization in the baseline regression and expenditure-based fiscal decentralization as a robustness test. Regarding financial decentralization (FINDE), we employ the ratio of year-end loan balances of local financial institutions to national financial institutions as an indicator. Additionally, as a robustness check, it examines the number of employees in municipal financial institutions relative to those in provincial (or municipal) financial institutions at the preceding level. This methodological approach ensures a comprehensive assessment of fiscal and financial decentralization dynamics in the context of the study's hypotheses.

#### 4.1.2. Dependent Variable

The dependent variable in this paper is green economic efficiency (EFF). Drawing on the methodology outlined by Tone (2002), this study employs the non-radial SBM-DEA model to calculate the green economic efficiency index [57]. This model requires setting input and output variables: inputs include capital, labor, and resource inputs, while outputs encompass desired and non-desired outputs, with 2003 as the base year. Labor input is measured by the total number of employees in society at the end of the year. For resource input (r), natural resources are categorized into land, energy, and water resources. Given the lack of municipal-level energy data, municipal electricity consumption is often substituted as a resource input, sourced from City Statistical Yearbooks. The desired output is local GDP converted to real GDP at constant 2003 prices. Non-desired outputs include waste, wastewater, and solid waste from industrial production processes. Due to data gaps in industrial three-waste emissions, this paper utilizes an average of the previous and subsequent years' data as a proxy.

#### 4.1.3. Control Variables

This paper includes several control variables: Referring to related scholars' studies [58,59], we choose the level of economic development (YPGDP), scientific research investment (TECH), level of regional industrial structure (STRU), city size (SIZE), environmental regulation (ER), level of education (YEDU), level of openness to the outside world (YOPEN), and infrastructure development (YINFRA). To address heteroskedasticity, economic development, city size, openness to the outside world, and education level are logarithmically transformed.

Level of Economic Development (YPGDP): This is measured by per capita GDP, which reflects regional economic growth. Higher per capita GDP is associated with specific impacts on green economy efficiency due to its relationship with industrial waste outputs. This variable is denoted as PGDP after logarithmization.

Scientific Research Investment (TECH): This variable measures the proportion of scientific and technological input in financial budget expenditures. Scholars generally believe that higher scientific research investment improves environmental quality, although it may also crowd out funds earmarked for environmental protection.

Level of Regional Industrial Structure (STRU): This is gauged by the proportion of the secondary industry's added value to GDP. The secondary industry, particularly the heavy industry, contributes to energy consumption and environmental pollution. A higher proportion of the secondary industry typically correlates with poorer environmental quality.

City Size (SIZE): This is determined by the population-to-administrative-area ratio of each city. Population size impacts the urban environment through scale and agglomeration effects. Larger populations may increase demand for housing and vehicles, leading to environmental degradation, though agglomeration can enhance public transport and shared emission reduction facilities.

Environmental Regulation (ER): The level of ecological regulation is crucial for addressing environmental issues. In this study, environmental regulation is measured using the comprehensive utilization rate of industrial solid waste, following practices from previous research.

Level of Education (YEDU): The education level is assessed by the number of educators per 10,000 people. Higher education levels typically correlate with increased awareness and demand for ecological quality. However, the rapid expansion of educational institutions does not always translate to local development.

Level of Openness to the Outside World (YOPEN): This is measured by the total imports and exports at the municipal level, indicating foreign trade dependence. The impact of openness on environmental quality is debated between theories like the "pollution halo" and "pollution refuge". Logarithmization transforms this variable, denoted as OPEN.

Infrastructure Development (YINFRA): Urban infrastructure improvements, represented here by postal and telecommunication business volume, can reduce transaction costs and potentially mitigate urban pollution. INFRA denotes this variable after logarithmization.

### 4.2. Weighting Matrix Construction

Determining the spatial weight matrix is foundational to spatial econometric model analysis. Commonly used matrices include geographic distance spatial weights, which use Anselin's inverse distance square spatial matrix based on city coordinates to measure distances, and economic distance spatial weights, which consider economic development levels and transportation infrastructure linkages [60,61]. This paper constructs both a geospatial weight matrix and an economic nested matrix. The geospatial weight matrix comprises two components: the neighborhood space weight matrix and the distance space weight matrix, formulated as follows:

$$W_{ij}{}^{0\text{–}1} = \begin{cases} 1 & \text{bordering two cities} \\ 0 & \text{The two cities are not adjacent} \end{cases}$$

$$W_{ij}{}^{d} = e^{-\alpha d_{ij}}$$

In the above equation, $W_{ij}{}^{0\text{–}1}$ represents the 0–1 neighborhood weight matrix, and $i$ and $j$ represent geographic units, respectively; $W_{ij}{}^{d}$ represents the distance weight matrix $d_{ij}$ anddoes represents the distance between two geographic units.

To portray the complex spatial development of green economic efficiency considering both geographic and economic factors, a weighted economic matrix is calculated. This approach integrates geographic influences with economic characteristics to comprehensively analyze green economic efficiency across different regions. The economic weight matrix is computed using the following framework:

$$W_{ij}{}^{e} = W_{ij}{}^{d} diag\left(\overline{Y_1}/\overline{Y}, \overline{Y_2}/\overline{Y}, \ldots, \overline{Y_n}/\overline{Y},\right)$$

In the above equation, $W_{ij}{}^{e}$ is the economic spatial weight matrix, $\overline{Y_i}$ is the average value of city $i's\ GDP$ from 2003 to 2018, and $\overline{Y}$ is the average value of all regions.

### 4.3. Data Description

In this study, data from 285 cities between 2004 and 2019 were collected from various statistical websites, including the Wind database, the EPS database, statistical bulletins of each city, the CSMR database, and the CEIC database. Cities that did not meet data quality and availability criteria were excluded through rigorous data cleaning processes.

Specifically, the fiscal decentralization (FISDE) data were obtained from the EPS and CSMR databases, which mutually complement and corroborate each other across different years, ensuring comprehensive sample data and data reliability. The financial decentralization (FINDE) data were also sourced from the EPS and CSMR databases, similarly complementing each other across various years. Additionally, the FINDE data from the CEIC database were used, and in robustness tests, employee data from financial institutions were sourced from the Wind database, with missing values filled through linear difference interpolation. The interaction term (FINFIS), crucially derived from the product of fiscal and financial decentralization, was computed accordingly.

In terms of the dependent variable, green economic efficiency (EFF), we utilized a non-radial SBM-DEA model to calculate the green economic efficiency index. Input variables such as capital, labor, and resource inputs, as well as desired and undesired output data, were sourced from the statistical yearbooks of each respective city.

Similarly, all control variables were gathered from the statistical yearbooks of the corresponding cities.

The descriptive statistics in Table 1 reveal significant variations among the variables. Financial decentralization ranges from a minimum of 0.139 to a maximum of 0.912, while fiscal decentralization ranges from 0.00005 to 0.443. Green economy efficiency ranges from a minimum of 0.074 to a maximum of 1. The substantial standard deviations indicate pronounced financial disparities among regions, underscoring the need for local governments to strategically allocate regional financial resources to address economic imbalances. Overall, the dataset is robust and provides a comprehensive representation of the cities under study.

**Table 1.** Summary of indicator selection.

| Var | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| FISDE | 4560 | 0.385 | 0.105 | 0.139 | 0.912 |
| FINDE | 4560 | 0.012 | 0.029 | 0.00005 | 0.443 |
| EFF | 4560 | 0.375 | 0.158 | 0.074 | 1 |
| PGDP | 4560 | 10.164 | 0.896 | 7.568 | 13.215 |
| TECH | 4560 | 0.182 | 0.231 | 0.002 | 6.31 |
| STRU | 4560 | 3.842 | 0.251 | 2.695 | 4.511 |
| SIZE | 4560 | 5.722 | 0.932 | 1.547 | 7.882 |
| ER | 4560 | 78.056 | 23.478 | 0.24 | 100 |
| EDU | 4560 | 1.389 | 0.731 | −2.526 | 4.021 |
| OPEN | 4560 | 13.411 | 2.213 | 2.781 | 21.143 |
| FINFIS | 4560 | 0.006 | 0.018 | 0.00002 | 0.264 |
| INFRA | 4560 | 12.121 | 1.206 | 0.298 | 16.452 |

*4.4. Modelling Construction*

Based on the literature demonstrating the spatial agglomeration of green economic efficiency [62], this study employs a spatial econometric model to investigate the influence of fiscal decentralization, financial decentralization, and their interaction on green economic efficiency. The spatial econometric model encompasses three main specifications: spatial lag, spatial error, and spatial Durbin models (SDM). Initially, this paper assumes a general spatial Durbin model. Subsequently, it conducts diagnostic tests such as the likelihood ratio (LR) test and Wald test. If these tests do not meet the required criteria, the model may be simplified to either a spatial lag model or a spatial error model (SEM). Conversely, if the spatial Durbin model is supported by the diagnostic tests, it will be retained for further analysis. This approach allows for a rigorous examination of how fiscal and financial decentralization, individually and jointly, impacts green economic efficiency while accounting for spatial dependencies among regions.

$$
\begin{aligned}
EFF_{it} = \alpha_0 + \rho \sum_{j=1}^{n} \omega_{ij} EFF_{jt} + \alpha_1 FISDE_{it} + \delta_1 \sum_{j=1}^{n} \omega_{ij} FISDE_{it} + \alpha_2 FINDE_{it} \\
+ \delta_2 \sum_{j=1}^{n} \omega_{ij} FINDE_{it} + \alpha_3 FINFIS_{it} + \delta_2 \sum_{j=1}^{n} \omega_{ij} FINFIS_{it} + \alpha_4 X_{it} + \mu_i + \theta_t + \varepsilon_{it}
\end{aligned}
$$

The above equation is the formula of the general spatial Durbin model, where $EFF_{it}$ represents the green economic efficiency of the city $i$ in year $t$, $\rho$ reflects the spatial autoregressive model (SAR) coefficient of the magnitude of the spatial spillover effect of the municipal green economic efficiency, $\delta$ is the spatial regression coefficient of the independent variables, $\omega_{ij}$ reflects the spatial weight matrix, $FISDE_{it}$, $FISDE_{it}$, and $FINFIS_{it}$ represent the fiscal decentralization, financial decentralization, and the cross-multiplication of fiscal decentralization and financial decentralization in year $t$ of the city $i$, respectively, and $X_{it}$ is a series of control variables. It represents the fiscal decentralization, financial decentralization, and the cross-multiplier of fiscal decentralization and financial decentralization of city $i$ in year $t$. $X_{it}$ is a series of control variables, $\mu_i$ represents the individual effect, $\theta_t$ represents the time effect, and $\varepsilon_{it}$ represents the random error term.

## 5. Empirical Results and Analysis

### *5.1. Spatial Correlation*

To explore spatial spillovers, it is imperative to assess spatial correlations between regions, including spatial autocorrelation analysis and measurements of spatial correlations and agglomeration patterns. Common practices involve conducting spatial autocorrelation tests using Moran's index and Moran's scatterplot. This paper employs Moran's index to assess the spatial correlation of fiscal and financial decentralization's impact on green economic efficiency. Moran's index ranges from −1 to 1, with higher values indicating stronger spatial dependence on green economic efficiency. The analysis results presented in Table 2 indicate that across three spatial weighting matrices, green economic efficiency shows significant spatial correlation at the 1% level in most cases. This underscores the presence of spatial patterns in how fiscal and financial decentralization influence green economic outcomes.

**Table 2.** Moran Index.

| EFF | Distance Weighting | 0–1 WEIGHTING | Nested |
|---|---|---|---|
| 2004 | 0.000 *** | 0.000 *** | 0.000 *** |
| 2005 | 0.000 *** | 0.000 *** | 0.000 *** |
| 2006 | 0.000 *** | 0.000 *** | 0.001 *** |
| 2007 | 0.000 *** | 0.000 *** | 0.001 *** |
| 2008 | 0.001 *** | 0.000 *** | 0.002 *** |
| 2009 | 0.062 * | 0.000 *** | 0.005 *** |
| 2010 | 0.135 | 0.000 *** | 0.002 *** |
| 2011 | 0.005 *** | 0.000 *** | 0.005 *** |
| 2012 | 0.001 *** | 0.000 *** | 0.000 *** |
| 2013 | 0.000 *** | 0.000 *** | 0.000 *** |
| 2014 | 0.026 ** | 0.000 *** | 0.278 |
| 2015 | 0.005 *** | 0.000 *** | 0.158 |
| 2016 | 0.000 *** | 0.000 *** | 0.074 * |
| 2017 | 0.001 *** | 0.000 *** | 0.015 ** |
| 2018 | 0.000 *** | 0.000 *** | 0.007 *** |
| 2019 | 0.000 *** | 0.000 *** | 0.000 *** |

Note: *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

Territorial spatiality provides an overview of the overall spatial correlation of variables but may overlook the unique characteristics of local areas [60]. To capture the spatial clustering of green economic efficiency more comprehensively, this study employs a local Moran scatterplot. This plot delineates the spatial clustering of urban green economic efficiency, offering insights into the distribution patterns across different types of regions. The four quadrants of the local Moran scatterplot classify the distinctive properties associated with varying levels of green economic efficiency. Detailed results are depicted in Figure 1.

This study focuses on the period of 2004–2019. This timeframe begins with China's promulgation of the "Outline of the Medium and Long-term Development Plan for Energy (2004–2020) (Draft)", marking the initiation of enhanced green economy efficiency efforts in China. The study concludes in 2019 due to the significant uncertainties introduced by the 2020 epidemic, which could potentially bias the study's findings through endogenous impacts and exogenous shocks.

The distribution of cities shows that observation points are not evenly spread across the four quadrants, indicating spatial autocorrelation in the research sample. Most cities exhibiting green economic efficiency are concentrated in the second and third quadrants. The second quadrant signifies low local green economic efficiency surrounded by high efficiency in neighboring areas. Conversely, the third quadrant indicates high local green economic efficiency with low efficiency in adjoining regions. These findings suggest a potential "warning effect" regarding the development level of green economic efficiency, which requires validation through rigorous econometric analysis in subsequent steps.

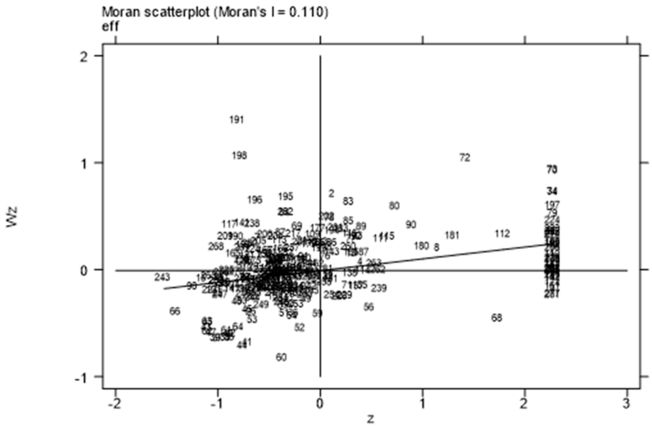


**Figure 1.** Localized Moran diagram in 2019.

### *5.2. LM Test*

The existing literature commonly examines spatial effects using the Lagrange multiplier test (LM test) and robust LM test (RLM test) to determine if the spatial Durbin model can be simplified to a spatial lag model or a spatial error model [63]. Table 3 presents the test outcomes on whether the spatial Durbin model can be reduced to a spatial lag model or a spatial error model across various weight matrices. It is observed that the LM test yields significant results consistently across different matrix conditions and robustness tests. This signifies that the econometric model employed in this study is suitable for adopting the spatial Durbin model.

**Table 3.** LM test.

| | | Inverse Distance | 0–1 | Nested |
|---|---|---|---|---|
| SAR | LM | 738.235 *** | 406.976 *** | 365.286 ** |
| | | (0.000) | (0.000) | (0.000) |
| | RLM | 353.275 *** | 37.687 *** | 175.713 *** |
| | | (0.17) | (0.000) | (0.000) |
| SEM | LM | 393.743 *** | 374.742 *** | 204.028 *** |
| | | (0.000) | (0.000) | (0.000) |
| | RLM | 9.233 *** | 5.452 ** | 14.455 *** |
| | | (0.002) | (0.020) | (0.000) |

Note: (1) *p*-values are in parentheses; (2) *** denotes significant within 1 percent and ** denotes significant within 5 percent.

### *5.3. LR Test*

As depicted in Table 4, following the Likelihood ratio test (LR test), the spatial Durbin model cannot be reduced to either a spatial autoregressive model or a spatial error model across any weight matrix. Consequently, this model is selected for analysis in this paper.

**Table 4.** LR test results.

| | Inverse Distance | 0–1 | Nested |
|---|---|---|---|
| LR(SAR) | 269.08 *** | 2140.21 *** | 154.44 *** |
| | (0.000) | (0.000) | (0.000) |
| LR(SEM) | 86.17 *** | −3395.76 | 88.77 *** |
| | (0.000) | (1.000) | (0.000) |

Note: (1) *p*-values are in parentheses; (2) *** denotes significant within 1 percent.

*5.4. Baseline Regression Results*

Table 5 presents the regression results of the spatial Durbin model. As indicated in the table, fiscal decentralization has a significant negative impact on green economic efficiency (−0.2172), while its coefficient in the spatial lagged regression is notably positive (4.4530), both significant at the 1% level. This suggests that fiscal decentralization hinders local green economic efficiency but facilitates green development in neighboring regions. This paradoxical effect may stem from current promotion mechanisms where local governments prioritize high-polluting industries for short-term economic gains, thereby suppressing local green economic efficiency. Conversely, neighboring regions may improve their green economic efficiency due to a "warning effect" [64], where declining environmental quality prompts neighboring governments to enhance environmental protection under public pressure and regulatory scrutiny. Based on this, H1B is validated.

**Table 5.** Baseline regression results.

| | SDM | SAR | SEM |
|---|---|---|---|
| FISDE | −0.21723 *** | −0.16405 *** | −0.19002 *** |
| | (−4.12525) | (−3.14194) | (−3.60906) |
| FINDE | 1.23523 *** | 1.11475 ** | 1.05393 ** |
| | (2.59811) | (2.33057) | (2.20782) |
| FINFIS | 0.83458 | 1.14611 | 1.22144 |
| | (1.08237) | (1.47666) | (1.57876) |
| PGDP | 0.2215 *** | 0.20815 *** | 0.21826 *** |
| | (17.88158) | (17.97155) | (18.26345) |
| TECH | −0.00998 | −0.02137 ** | −0.0211 ** |
| | (−1.12992) | (−2.50225) | (−2.43357) |
| STEU | −0.03145 ** | −0.0526 *** | −0.04754 *** |
| | (−1.98314) | (−3.49265) | (−3.07896) |
| SIZE | −0.01222 | −0.05666 * | −0.05198 |
| | (−0.34382) | (−1.75128) | (−1.54202) |
| INFRA | 0.00001 *** | 0.00001 *** | 0.00001 *** |
| | (6.22631) | (6.57817) | (6.4811) |
| ER | 0.00004 | 0.00001 | 0.00002 |
| | (0.66739) | (0.13421) | (0.26921) |
| EDU | −0.06811 *** | −0.09014 *** | −0.08196 *** |
| | (−5.11126) | (−6.88983) | (−6.18314) |
| OPEN | −0.00308 | −0.00225 | −0.00194 |
| | (−1.11209) | (−0.81965) | (−0.7001) |
| W×FISDE | 4.45296 *** | | |
| | (6.06397) | | |
| W×FINDE | 31.21634 *** | | |
| | (4.76552) | | |
| W×FINFIS | −50.33751 *** | | |
| | (−4.51898) | | |
| W×PGDP | −0.16263 | | |
| | (−1.52985) | | |
| W×TECH | 0.35295 *** | | |
| | (3.39354) | | |
| W×STRU | 0.01522 | | |
| | (0.09642) | | |
| W×SIZE | 0.87371 *** | | |
| | (2.89338) | | |
| W×infra | 0.00004 * | | |
| | (1.92765) | | |
| W×ER | 0.00045 | | |
| | (0.54515) | | |
| W×EDU | −0.95052 *** | | |
| | (−5.60913) | | |
| W×OPEN | −0.12285 *** | | |
| | (−3.54356) | | |
| $\rho$ | 0.56851 *** | 0.67725 *** | |
| | (6.91591) | (10.44744) | |
| $\lambda$ | | | 0.70119 *** |
| | | | (11.20121) |
| $\sigma^2$ | 0.00759 *** | 0.00777 *** | 0.00776 *** |
| | (47.65037) | (47.59049) | (47.62262) |
| $R^2$ | 0.11482 | 0.12525 | 0.11188 |
| $N$ | 4560 | 4560 | 4560 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

Moreover, the regression coefficients in Table 5 show that financial decentralization positively impacts green efficiency (1.2352) and exhibits a significant facilitating effect on neighboring green economic efficiency (spatial lag coefficient of 31.2163), both significant at the 1% level. This indicates that financial decentralization not only enhances local green economic efficiency by enabling better allocation of local financial resources but also stimulates neighboring regions to improve their green economic performance. The "agglomeration effect" of financial decentralization may explain this, where local initiatives in improving green economy efficiency serve as a model for neighboring jurisdictions, encouraging them to prioritize environmental concerns. Based on this, H2A is validated.

Furthermore, the interaction term between fiscal decentralization and financial decentralization shows a coefficient of 0.8346, with its spatial lagged coefficient at −50.3375, significant at the 1% level. This suggests that fiscal decentralization inhibits green economy efficiency in neighboring regions. Based on this, H3A is validated.

Regarding control variables, economic development level, environmental regulations, and infrastructure development positively influence green economic efficiency. Conversely, variables such as industrial structure, science and technology investment, city size, education level, and openness negatively impact green economic efficiency. Specifically, a higher proportion of secondary industry in the industrial structure tends to hinder green economic efficiency, while significant investments in science and technology may divert resources away from environmental protection efforts. Additionally, larger city sizes contribute to environmental challenges due to increased waste and pollution, and higher levels of openness may attract polluting industries, thereby reducing regional green economic efficiency.

### *5.5. Durbin's Partial Differential Effect*

To mitigate the potential biases of the Durbin spatial model [63], this paper conducts a further decomposition and analyzes its effects, as presented in the subsequent Table 6. The indirect effects identified align with the spatial spillover effects reported in the preceding table. This further finding supports the baseline regression test results.

**Table 6.** Durbin partial differential effects.

| Variable | Direct Effect | Indirect Effect | Aggregate Effect |
|---|---|---|---|
| FISDE | −0.18049 ***<br>(−3.32062) | 10.42833 ***<br>(3.81808) | 10.24784 ***<br>(3.74235) |
| FINDE | 1.47071 ***<br>(3.14606) | 75.65545 ***<br>(3.3541) | 77.12616 ***<br>(3.40325) |
| FINFISH | 0.48476<br>(0.63576) | 117.858 ***<br>(−3.18911) | 117.3734 ***<br>(−3.15989) |
| PGDP | 0.2209 ***<br>(18.28558) | −0.09699<br>(−0.40188) | 0.12392<br>(0.51622) |
| TECH | −0.00741<br>(−0.86287) | 0.81715 ***<br>(2.70631) | 0.80975 ***<br>(2.66841) |
| STRU | −0.03034 *<br>(−1.93815) | 0.03962<br>(0.10237) | 0.00928<br>(0.02399) |
| SIZE | −0.00641<br>(−0.17697) | 1.99776 **<br>(2.52206) | 1.99136 **<br>(2.53269) |
| INFRA | 0.00001 ***<br>(6.66105) | 0.00011 **<br>(2.02627) | 0.00012 **<br>(2.22133) |
| ER | 0.00005<br>(0.83008) | 0.00111<br>(0.51896) | 0.00117<br>(0.54259) |
| EDU | −0.0755 ***<br>(−5.53836) | −2.3570 ***<br>(−4.05528) | −2.4325 ***<br>(−4.17288) |
| OPEN | −0.00419<br>(−1.51794) | −0.29805 ***<br>(−2.727) | −0.30224 ***<br>(−2.75345) |

Note: (1) *p*-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

### *5.6. Robustness Tests*

#### 5.6.1. Replacement Based on Satellite Light Data

Satellite light data, classified as remote sensing data, offers continuous monitoring capabilities of ground surface conditions, distinguishing it from statistical department data. Consequently, light data provides an enhanced method to gauge economic development levels. In this study, when assessing green economic efficiency, lighting data substitutes

GDP as the desired output. An approach is employed to integrate the Defense Meteorological Satellite Program (DMSP) and Visible Infrared Imaging Radiometer (VIIRS) data spanning 2003–2018 to derive lighting data. As depicted in Table 7, the conclusions remain consistent following the replacement of GDP with lighting data as the desired output.

**Table 7.** Replacement based on satellite light data.

| | Core Variable | W* Core Variable | Direct Effect | Indirect Effect | Aggregate Effect |
|---|---|---|---|---|---|
| FISDE | −0.0957 * | 3.4674 *** | −0.0847 * | 2.5588 *** | 2.474 *** |
| | (−1.9096) | (4.2365) | (−1.6475) | (3.5801) | (3.4508) |
| FINDE | 0.8421 * | 13.6217 *** | 0.8637 * | 11.0538 *** | 11.9176 *** |
| | (1.7323) | (4.7298) | (1.8431) | (5.0174) | (5.1388) |
| FINFIS | 1.1150 | −20.3338 *** | 1.1069 | −14.7349 *** | −13.6280 *** |
| | (1.4293) | (−4.4024) | (1.4677) | (−4.1193) | (−3.5929) |
| Control | Yes | Yes | Yes | Yes | Yes |
| W* Control | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.1503 | | . | | |
| $N$ | 4560 | | | | |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent and * denotes significant within 10 percent.

#### 5.6.2. Weight Matrix Replacement

Feng et al. (2022) argued that besides the commonly used distance-based spatial weight matrix, economic and social nested spatial weight matrices have gained prominence in regional economic research for their conceptual proximity-based approach [63]. In light of this, the current study substitutes the inverse distance matrix with a nested matrix for conducting robustness tests. As indicated in the robustness test results presented in Table 8, fiscal decentralization hinders local green economic efficiency improvement, while financial decentralization shows a positive coefficient. Additionally, the interaction between fiscal and financial decentralization is positively significant. Accounting for spatial spillover effects reveals that fiscal decentralization negatively impacts neighboring regions, with financial decentralization maintaining a positive coefficient. Notably, the fiscal–financial decentralization interaction term shows a negative coefficient, consistent with previous analyses, thereby affirming the robustness of the estimation results.

**Table 8.** Replacement weight matrix.

| | Nested | Changing the Measurement of Fiscal Decentralization | Changing Financial Decentralization Index |
|---|---|---|---|
| FISDE | −0.3183 *** | −0.22528 *** | −0.29265 *** |
| | (−6.3144) | (−4.73756) | (−5.16995) |
| FINDE | 1.21225 ** | 1.77383 *** | 2.83226 ** |
| | (2.52791) | (4.83901) | (2.43657) |
| FINFIS | 0.7877 | −0.11024 | 0.2981 |
| | (1.02368) | (−0.17769) | (1.5857) |
| W×FISDE | 1.23816 *** | 1.61106 *** | 4.2583 *** |
| | (3.05475) | (2.89283) | (5.54024) |
| W×FINDE | 2.66944 * | 26.99983 *** | 3.27138 ** |
| | (1.89781) | (4.31513) | (2.36551) |
| W×FINFIS | −5.13284 ** | −46.82695 *** | −2.57684 |
| | (−2.21019) | (−4.56572) | (−0.80896) |
| Control | Yes | Yes | Yes |
| W* Control | Yes | Yes | Yes |
| $R^2$ | 0.12973 | 0.0635 | 0.008782 |
| $N$ | 4560 | 4560 | 4560 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

## 6. Heterogeneity Tests

### *6.1. Spatial Variability*

Due to its expansive geographical size, China exhibits considerable disparities in financial resource allocation among its regions. Consequently, this study categorizes its research into three regions: East, Central, and West, encompassing 137, 73, and 75 cities, respectively, for analysis. Table 9 illustrates the effects of fiscal and financial decentralization, as well as their interaction, on green economic efficiency across these regions. According to the analysis in Table 9, the impact of fiscal and financial decentralization on green economic efficiency varies across regions. Financial decentralization demonstrates a significant negative direct impact across all three regions. Specifically, financial decentralization promotes green economic efficiency in the East and West regions, significant at the 1% level in the West but not statistically significant in the East. Conversely, financial decentralization inhibits green economic efficiency in the Central region, significantly at the 1% level. The promotional and inhibitory effects are notably pronounced in the Central and Western regions, with the promotion effect in the West and the inhibition effect in the Central region being particularly strong. The interaction between fiscal and financial decentralization exhibits a significant positive effect on the Central and East regions, albeit at different significance levels. In contrast, this interaction has a significantly negative effect on the Western region. Considering spatial spillover effects, fiscal decentralization's spillover effect is positive, with the most pronounced impact observed in the Eastern region. In contrast, financial decentralization's spillover effect is significantly negative in the Central region but significantly positive in both the Eastern and Western regions. Similarly, the spillover effect of the fiscal–financial decentralization interaction varies across regions, showing a significantly positive effect in the Central region but significantly negative effects in the other two regions. These findings underscore the heterogeneous impact of fiscal and financial decentralization under current decentralization practices, highlighting regional disparities in green economic efficiency outcomes.

**Table 9.** Regression results by region.

| | **Eastern** | **Middle** | **Western** |
|---|---|---|---|
| FISDE | −0.30342 *** | −0.22214 ** | −0.29296 *** |
| | (−4.18416) | (−2.55013) | (−2.69043) |
| FINDE | 0.23764 | −7.48631 *** | 15.34032 *** |
| | (0.3856) | (−3.689) | (4.93054) |
| FINFIS | 1.77621 * | 13.7908 *** | −26.71807 *** |
| | (1.83455) | (4.03628) | (−4.0531) |
| W×FISDE | 2.88913 *** | 2.04501 ** | 1.58621 ** |
| | (4.0298) | (2.19095) | (2.13938) |
| W×FINDE | 27.74822 *** | −61.2909 *** | 70.44854 *** |
| | (5.41424) | (−3.06599) | (2.95528) |
| W×FINFIS | −52.4878 *** | 79.27645 ** | −133.0957 *** |
| | (−6.3377) | (2.33201) | (−2.63851) |
| Control | Yes | Yes | Yes |
| W* Control | Yes | Yes | Yes |
| $R^2$ | 0.17915 | 0.26839 | 0.0567 |
| $N$ | 2192 | 1168 | 1200 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

### *6.2. Heterogeneity Test Based on Hu Huanyong Line*

The Hu Huanyong line, proposed by the renowned geographer Hu Huanyong in 1953, runs from Heilongjiang's Heihe to Yunnan's Tengchong. This line divides China into two regions: the southeastern part, which covers 36% of the country's area and houses 96% of its population, and the northwestern part, which spans 64% of the country's area but holds only 4% of its population. This stark spatial imbalance in population distribution underscores significant regional disparities in China. Population factors exert a notable influence on the regional environment. Therefore, this study conducts separate tests on both sides of the

Hu Huanyong line. Table 10 reveals that in the northwestern region, the impact of fiscal decentralization and financial decentralization on green economic efficiency is negative but not statistically significant. This outcome may be attributed to the smaller sample size in the northwest area of the Hu Huanyong line. In contrast, in the southeastern region of the Hu Huanyong line, fiscal decentralization demonstrates a significantly negative impact on local environmental development. Financial decentralization, on the other hand, contributes positively to local green efficiency, albeit not significantly. Moreover, the spatial spillover effects differ across regions. Financial decentralization exhibits a significantly positive spillover effect in the southeastern part of the Hu Huanyong line but a negative spillover effect in the northwestern part. The spillover effect of fiscal decentralization also varies along the Hu Huanyong line. These findings underscore the nuanced impacts of fiscal and financial decentralization on green economic efficiency in different regions divided by the Hu Huanyong line, highlighting the importance of considering regional context in environmental policy and planning.

**Table 10.** Trend of Moran's I index under geographic distance weight matrix.

| | **Hu Huanyong Line Southeast** | **Hu Huanyong Line Northwest** |
|---|---|---|
| FISDE | −0.23838 *** | −0.00295 |
| | (−4.44527) | (−0.0149) |
| FINDE | 0.71693 | −10.48729 |
| | (1.57399) | (−1.55158) |
| FINFIS | 1.47354 ** | 40.74861 *** |
| | (1.99126) | (2.85322) |
| W×FISDE | 4.0035 *** | 1.40789 |
| | (5.83608) | (1.28483) |
| W×FINDE | 33.80954 *** | −79.11105 ** |
| | (5.64886) | (−2.07838) |
| W×FINFIS | −58.40028 *** | 208.13247 ** |
| | (−5.73483) | (2.53877) |
| Control | Yes | Yes |
| W* Control | Yes | Yes |
| $R^2$ | 0.14078 | 0.0455 |
| $N$ | 4096 | 464 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent.

### *6.3. Tests for Temporal Heterogeneity*

Since 2000, local financial decentralization in China has generally been limited. In response to the 2008 financial crisis, the central government began granting local governments greater authority in credit intervention from 2009 onward. This trend continued until the Third Plenary Session of the 18th Central Committee in 2013, which marked the formalization of efforts to improve the financial market system and solidify financial decentralization. Given these developments, this study sets time nodes in 2008 and 2013 to analyze their respective impacts. From the analysis presented in Table 11, it is evident that the influence of financial decentralization on local and neighboring green economic efficiency varies across different periods. Between 2004 and 2013, financial decentralization and its spillover effects negatively impacted green economic efficiency. However, from 2014 onwards, financial decentralization began playing a stimulating role in enhancing green economic efficiency. This shift can be attributed to the imperfections in the financial market system before the Third Plenary Session of the 18th Central Committee. As the system improved post-2013, financial decentralization became more effective in promoting green economic efficiency. Regarding the synergistic effect of fiscal and financial decentralization, it facilitated green economic efficiency between 2004 and 2013. Conversely, its spillover effect turned negative during 2014–2019. This suggests that while financial decentralization showed positive impacts post-2014, the overall spillover effects in subsequent years were less favorable. These findings highlight the evolving nature of financial decentralization's impact on green economic efficiency, emphasizing the importance of institutional improvements and policy context in shaping environmental outcomes.

**Table 11.** Regression results by period.

| | 2004–2008 | 2009–2013 | 2014–2019 |
|---|---|---|---|
| FISDE | −0.22471 *** | −0.36974 *** | −0.01963 |
| | (−3.47706) | (−5.64798) | (−0.1488) |
| FINDE | −3.63198 * | −6.54202 *** | 1.82572 |
| | (−1.77535) | (−6.34586) | (1.63228) |
| FINFIS | 6.8484 ** | 10.56543 *** | 0.37689 |
| | (1.98776) | (6.34964) | (0.21071) |
| W×FISDE | 3.74792 *** | 0.24995 | 6.53706 *** |
| | (4.44794) | (0.25882) | (3.77719) |
| W×FINDE | −32.80195 | −29.24908 ** | 47.04056 *** |
| | (−1.53101) | (−2.39994) | (3.15476) |
| W×FINFIS | 75.32232 * | 57.59591 *** | −68.27365 *** |
| | (1.90101) | (2.72512) | (−2.81828) |
| Control | Yes | Yes | Yes |
| W* Control | Yes | Yes | Yes |
| $N$ | 1425 | 1425 | 1710 |
| $R^2$ | 0.04838 | 0.15501 | 0.02506 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

### *6.4. Heterogeneity Test of Urban Infrastructure Construction*

Transport infrastructure, particularly urban rail transit, plays a crucial role in urban development, and its impact on air pollution has been noted by recent researchers [60,63]. This study categorizes cities based on whether they have operational rail transit systems, using data from the Ministry of Transportation and Communications "2020 Urban Rail Transit Operation Data Express". Cities are divided into those with and without rail transit to analyze the spatial effects separately. According to the analysis results in Table 12, regardless of the state of infrastructure development, financial decentralization consistently shows a negative effect on green economic efficiency. However, its spillover effect on green economic efficiency is significantly positive. Specifically, financial decentralization negatively impacts cities without rail transit, whereas it has a positive effect on cities that have already implemented rail transit. This difference may stem from the fact that cities with rail transit tend to be economic hubs with more robust financial resources and well-developed financial markets. Furthermore, the synergistic effect of fiscal and financial decentralization is significantly positive for improving green economic efficiency in cities without rail transit. In contrast, this effect is positive but not statistically significant for cities with rail transit. These findings underscore the varying impacts of fiscal and financial decentralization depending on the presence of rail transit infrastructure. Cities without rail transit may benefit more from decentralization policies in enhancing green economic efficiency, while cities with established rail transit systems exhibit mixed results, possibly due to their already advanced economic development and infrastructure.

**Table 12.** Sub-transport infrastructure regression results.

| | Cities without Metro | Cities with Metro |
|---|---|---|
| FISDE | −0.24237 *** | −0.31881 ** |
| | (−4.09974) | (−2.4936) |
| FINDE | −4.05434 ** | 1.22937 * |
| | (−2.08763) | (1.6589) |
| FINFIS | 20.9746 *** | 0.80529 |
| | (4.62766) | (0.69101) |
| W×FISDE | 3.40787 *** | 0.52352 |
| | (4.60247) | (0.63182) |
| W×FINDE | 107.2138 *** | 13.00892 *** |
| | (3.37826) | (4.27235) |
| W×FINFIS | −256.033 *** | −25.7968 *** |
| | (−3.50862) | (−5.22903) |
| Control | Yes | Yes |
| W* Control | Yes | Yes |
| $R^2$ | 0.10639 | 0.2989 |
| $N$ | 3872 | 688 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

## 7. Realization of Dynamic Spatial Measurement

Drawing on the insights of Shao et al. (2011), who proposed a path-dependent feature in the changes in carbon emissions over time and highlighted a bidirectional causal relationship with economic growth and technological progress, this paper integrates a lagged period of green economy efficiency into the static spatial Durbin model described earlier [64]. This extension allows for the construction of a dynamic Durbin model, which aims to capture the temporal dynamics and potential feedback loops between green economy efficiency, economic growth, technological advancements, and other relevant factors.

$$\begin{aligned} EFF_{it} = \lambda EFF_{it-1} \quad & + \alpha_0 + \rho \sum_{j=1}^{n} \omega_{ij} EFF_{jt} + \alpha_1 FISDE_{it} + \delta_1 \sum_{j=1}^{n} \omega_{ij} FISDE_{it} \\ & + \alpha_2 FINDE_{it} + \delta_2 \sum_{j=1}^{n} \omega_{ij} FINDE_{it} + \alpha_3 FINFIS_{it} \\ & + \delta_2 \sum_{j=1}^{n} \omega_{ij} FINFIS_{it} + \alpha_4 X_{it} + \mu_i + \theta_t + \varepsilon_{it} \end{aligned}$$

Utilizing a dynamic panel approach helps mitigate endogeneity issues inherent in static panel models, thereby enhancing the credibility of the findings in this study. As shown in Table 13, the short-term effects reveal significant impacts of fiscal decentralization, financial decentralization, and their interaction on green economy efficiency. However, in the long term, none of these variables—fiscal decentralization, financial decentralization, or their interaction—demonstrate a significant effect on green economy efficiency. This suggests that while fiscal and financial decentralization may exert immediate influences on green economic outcomes, these effects do not persist over the long term. This could imply that other factors, such as institutional changes, technological advancements, or policy adjustments, may play a more substantial role in shaping green economy efficiency in the extended period, as shown in Table 14.

**Table 13.** Dynamic spatial measurement regression results.

| | SDM | SAR |
|---|---|---|
| L.eff | 0.83106 *** | 0.64728 *** |
| | (61.04754) | (45.98957) |
| L.Weff | −0.12087 *** | −0.08514 *** |
| | (−51.53169) | (−48.11278) |
| FISDE | −0.09628 ** | 0.05233 |
| | (−2.05138) | (1.08571) |
| FINDE | −3.32638 *** | −0.10389 |
| | (−7.80591) | (−0.23524) |
| FINFIS | 5.84694 *** | 1.25864 * |
| | (8.48219) | (1.75667) |
| W×FISDE | 0.18862 *** | |
| | (19.96237) | |
| W×FINDE | −1.43079 *** | |
| | (−13.56936) | |
| W×FINFIS | 1.50897 *** | |
| | (8.45159) | |
| Control | Yes | Yes |
| W* Control | Yes | Yes |
| $R^2$ | 0.00784 | 0.06186 |
| $N$ | 4560 | 4560 |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent, ** denotes significant within 5 percent, and * denotes significant within 10 percent.

**Table 14.** Comparison of long- and short-term effects of dynamic spatial measurement.

| | Short-Term Effect | | | Long-Term Effect | | |
|---|---|---|---|---|---|---|
| | Direct Effect | Indirect Effect | Aggregate Effect | Direct Effect | Indirect Effect | Aggregate Effect |
| FISDE | −0.2110 *** | −0.7120 *** | −0.9230 *** | −0.9755 | −0.2626 | −1.23822 |
| | (−5.6396) | (−10.5019) | (−17.4148) | (−0.1456) | (−0.3641) | (−0.16713) |
| FINDE | −1.5321 *** | 10.6653 *** | 9.1331 *** | 6.4704 | 14.1318 | 20.6022 |
| | (−4.5440) | (14.1708) | (14.8327) | (0.0168) | (0.3472) | (0.04861) |
| FINFIS | 3.4379 *** | −14.3226 *** | −10.8846 *** | −6.5655 | −22.0074 | −28.57307 |
| | (6.4109) | (−11.5026) | (−10.5268) | (−0.0109) | (−0.3441) | (−0.04292) |

Note: (1) T-values are in parentheses; (2) *** denotes significant within 1 percent.

## 8. Discussion and Conclusions

### *8.1. Discussion*

In light of the above analyses, it becomes evident that fiscal decentralization appears to inhibit green economic efficiency overall but has a facilitative effect on efficiency in peripheral regions. This finding may initially seem unexpected, as conventional wisdom among scholars often posits that fiscal decentralization generally enhances economic efficiency [65,66]. However, our study contradicts this belief, attributing this to the phenomenon of a "GDP race" among regional governments competing for central government support [35]. Furthermore, fiscal decentralization empowers local governments, potentially influencing environmental governance expenditures. Some argue that this empowerment might prioritize economic development over environmental protection [36,37]. Financial decentralization impacts green economy efficiency both positively and negatively across regions. Some scholars argue that while fiscal decentralization may initially hinder local green economic efficiency, it can stimulate neighboring regions due to comparative advantage [67]. Local governments, motivated by increased decentralization, tailor development strategies to leverage local strengths, thus fostering an inter-regional "environmental race" that necessitates enhanced environmental protection and oversight. This competition generates positive spillover effects [34].

Moreover, empirical findings align with previous research, indicating that financial decentralization promotes local enterprise innovation, thereby enhancing China's green economic efficiency [52]. Increased financial autonomy invigorates local financial development and mitigates environmental pollution [51]. However, it may also lead to non-performing assets, undermining green economy efforts in neighboring regions, despite meeting the financial needs of local enterprises and governments [49].

Our study highlights significant regional heterogeneity in fiscal decentralization across China, influenced by diverse natural and financial endowments. This diversity manifests in pronounced differences between eastern and western regions, corroborating prior research [68]. Notably, mature financial markets and robust regional infrastructure are pivotal in shaping the impact of fiscal and financial decentralization on green economy efficiency. Improved infrastructure helps mitigate inter-regional disparities in factor endowments, thereby bolstering green economy efficiency nationwide [69].

### *8.2. Conclusions*

From promoting an "environmentally friendly society" to embracing the "two mountains theory", the Chinese government has consistently placed environmental sustainability at the forefront of its economic agenda. The decentralized governance system has provided a robust framework for China's economic development. While scholars have extensively examined the relationship between financial decentralization and environmental outcomes, the significant impact of financial decentralization—often considered the "elephant in the room"—has been frequently overlooked.

Fiscal decentralization and financial decentralization are closely related and synergistic, yet they are not synonymous. Existing studies often overlook the coexistence of synergistic and non-synergistic regions, failing to distinguish between these two forms and analyze them separately. Addressing this gap, this paper analyzes data from 285 cities across China from 2004 to 2019. It constructs a comprehensive framework to assess financial decentralization's dual roles: inhibiting local green economic efficiency while stimulating it in peripheral regions. Furthermore, financial decentralization promotes green economic efficiency in both local and peripheral contexts. Second, the synergistic effects of financial decentralization incentivize local green economic efficiency but adversely affect green economic efficiency in surrounding areas. Third, economic decentralization's impact on green economic efficiency varies across China, with a more consistent interaction observed in eastern and western regions.

However, financial decentralization uniquely impedes environmental development in the central region and its surrounding areas. Fourth, the gradual maturation of the financial market system and improvements in regional infrastructure positively influence the efficacy of financial decentralization on green economic efficiency. Finally, dynamic analysis reveals that while China's current financial decentralization has a significant short-term impact on green economy efficiency, its long-term effects are less pronounced.

This study examines fiscal decentralization, financial decentralization, and their impact on green economic efficiency. However, it faces limitations, particularly regarding data processing due to the study period ending in 2019. This restricts our understanding of the latest dynamics in China's fiscal and financial decentralization and their effects on green economic efficiency. Moreover, the post-2019 data samples were excluded due to potential endogeneity issues and exogenous shocks stemming from the COVID-19 pandemic. Consequently, future research will seek appropriate models to mitigate pandemic-related challenges and enhance the study's relevance. Additionally, this study offers a China-centric case that could be extrapolated to other nations, provided they possess fiscal and financial decentralization systems akin to China's. Future studies will explore this aspect further.

### 8.3. Policy Recommendations

Based on the findings of this study, the following policy recommendations are proposed to foster the advancement of fiscal and financial decentralization and promote green economy efficiency in China. These recommendations also aim to provide valuable insights for other developing countries striving to balance economic sustainability and natural resource management.

Firstly, it is important to establish standardized institutional safeguards to reinforce the central government's oversight of fiscal and financial decentralization among local governments, thereby enhancing green economic efficiency. While decentralization theory suggests that the decentralization system's design is inherently beneficial and logical, practical implementation reveals that local governments often resort to numerous "innovations" at both fiscal and financial levels to circumvent regulatory constraints. This overreliance on such policy tools has accumulated substantial risks that cannot be resolved quickly, posing challenges to long-term development. Therefore, the central government should implement measures such as quota management, local bond issuance regulations, and debt restructuring to mitigate these risks and promote efficient green economic development. Furthermore, coordinated fiscal and financial reforms are essential to establish a comprehensive policy framework integrating fiscal, financial, and green economic efficiency, encouraging proactive participation from local governments. This approach aims to rationalize and standardize decentralization practices, thereby enhancing green economic efficiency.

Secondly, it is crucial to enhance the alignment between fiscal decentralization, financial decentralization, and the green economy development model. The choice of fiscal decentralization, financial decentralization, and the green economic development model involves mutual cooperation and dynamic change processes. However, it is evident that fiscal decentralization and financial decentralization are not adequately aligned, primarily due to their differing impacts on green economy efficiency. Addressing this mismatch requires addressing its root causes. The evolution of decentralization systems should prioritize standardization, transparency, and rationalization, transforming local governments from mere "financiers" to effective "supervisors". Specifically, this involves refining financial and fiscal decentralization mechanisms to reduce local financial disparities while linking financial authority to environmentally sustainable development principles. This adjustment aims to diminish incentives for local governments to prioritize economic development over environmental concerns, enabling them to foster green economy initiatives through standardized, market-oriented approaches.

Finally, local governments need to deepen their understanding of the concepts of green economy and sustainable development. Green development aims for economic growth and social advancement while prioritizing efficiency, harmony, and sustainability. In regional economic planning, it is essential to consider local heterogeneities such as varying factor endowments and environmental capacities. Enhancing resource utilization efficiency and pursuing balanced economic, social, and environmental development are critical goals. The central government has introduced policies aimed at fundamentally resolving conflicts between economic development and environmental constraints. Capitalizing on industrial opportunities arising from the green economy, these policies are tailored to local conditions, offering robust guidance and planning. This comprehensive approach embeds green development principles across all aspects of economic and social progress. Initiatives are underway to accelerate the low-carbon transformation of traditional industries, nurture green sectors, and leverage digital technologies to enhance resource efficiency. These efforts are aimed at achieving sustainable development in regional green economies and enhancing overall "green welfare" in production and daily life.

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