




Research Article

Technological Innovation, Emerging Industrial Agglomeration, and High-Quality Green Development

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Received 1 April 2022; Revised 11 August 2022; Accepted 26 September 2022; Published 5 October 2022

Academic Editor: A. M. Bastos Pereira

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Exploring the transformation of the mode of economic growth has been widely concerned by researchers around the world, especially in the context of “dual carbon” goals. China’s economy is in a transition stage to high-quality green development (HGD), with technological innovation (TI) and emerging industrial agglomeration (EIA) as important drivers. However, existing studies lack a systematic empirical analysis on different dimensions of TI and its influence mechanism. In order to examine the mechanism of TI affecting HGD through EIA, this study uses the panel data in the western Yangtze River Delta of China from 2009 to 2019 to first comprehensively calculate the TI index, EIA index, and the HGD index as proxy variables for regional TI, EIA, and HGD, respectively, and then empirically examines the impact of TI on HGD and the heterogeneous impacts on HGD. Finally, we test the mediation effect of EIA between TI and HGD. The results show that TI effectively promotes regional HGD, and with the increase in the HGD index, the driving role of TI also increases. Technological innovation has heterogeneous impacts on HGD at different dimensions of innovation, time periods, and regions. Innovation output and diffusion have significant impacts on HGD, whereas innovation input and environment have insignificant impacts. The effects of TI promoting HGD are different before and after 2013. Additionally, the nexus between TI and HGD also differs across spatial distributions. The mediation effect indicates that EIA is an important mechanism for TI to release the dividends of HGD, and it explains approximately 29% of the conduction effect.

1. Introduction

In recent decades, high-quality green development (HGD) has become a prominent global issue faced by most countries in the world. There has been increasing attention to green growth, green economy, sustainable development, and high-quality economic development around the HGD [1–7]. China’s economy has witnessed high-speed growth but unbalanced social and severe environmental issues since the reform and opening-up policy in 1978 [8]. The economic growth path heavily relies on resource utilization and energy consumption. Rapid economic development has not only brought about severe environmental crises and ecological

imbalances but has also resulted in social issues, such as air pollution, excessive carbon emissions, unbalanced distribution of wealth, and inequitable health care [2, 9]. Especially in the context of the carbon peak and carbon neutrality, it is of great theoretical and practical significance to clarify the mechanism among technological innovation (TI), emerging industrial agglomeration (EIA), and HGD for correctly understanding the process of high-quality economic development, so as to scientifically formulate regional innovation, industrial upgrading, and high-quality development policies.

The Chinese government has been committing to relying on innovation-driven strategies to achieve HGD [10]. The

Yangtze River Delta (YRD), which has attracted increasing attention from the government and academia in recent years [11], is an innovation-driven belt leading China's HGD. The integrated development of the YRD has a demonstrative effect on the realization of the leap from "Chinese speed" to "Chinese quality." The construction of "Three Places and One Zone," namely, the source place of technological innovation (TI), the gathering place of emerging industries, the high place with a new level of reform and opening-up, and the comprehensive green transformation zone for economic and social development, is an important regional policy to realize the "30•60" goal of carbon peak and carbon neutrality in the western YRD. It is an effective way to lead the high-quality development and the integrated construction of the YRD. It is also a strategic measure for the construction of a modern and beautiful western YRD during this new stage. Therefore, how to effectively release the boosting power of TI to HGD in the western YRD has profound significance.

Existing studies on TI, green transformation development, high-quality economic growth, and innovation-driven sustainable development were relatively abundant and have laid the foundation for this study of TI on HGD [1–15]. However, the current literature may still ignore the following considerations. First, previous studies have discussed a series of factors in improving HGD, focusing on environmental regulation [16–18], foreign direct investment [19], and industrial structure upgrading [20]; and some scholars have also conducted studies by examining three variables [21–23]. However, to the best of our knowledge, our work incorporates the three variables, namely, TI, EIA, and HGD, into a unified framework under the construction of the "Three Places and One Zone" in the western YRD, which is an unexplored issue. Second, most studies consider the different dimensions of innovation separately, such as research and development (R&D) investment [24, 25], innovation output (patents and new products) [11, 16], or even just patents [8, 23, 26, 27]; and rarely simultaneously conduct a systematic analysis of multidimensional and single-dimensional innovations. However, we believe that TI is a multidimensional concept, which is challenging to characterize using a single index, whereby we measure a composite index to express TI. Third, the measurement of green development or green growth merely focuses on efficiency [1, 8], but the equity of the economy, namely, "people's green life," is not incorporated, such as the sharing of education, providing medical care, and the narrowing of the income gap [2]. Finally, with the development of TI, emerging industries have inevitably played a vital role in HGD [28]. In particular, the Chinese government issued policies on EIA to pursue sustainable development. However, the literature is still not sufficient for EIA to affect HGD. Therefore, the nexus between TI and HGD is an issue worthy of in-depth discussion.

Therefore, using panel data covering 16 cities in the western YRD from 2009 to 2019, this paper measures the composite TI and HGD indices, and then puts the three variables, namely, TI, EIA, and HGD, into the same research framework to empirically identify the impact of TI on HGD, the heterogeneity, and the influence mechanism, trying to

answer the following subquestions: (1) Does TI promote HGD in the western YRD? (2) What differences do the driving effects have under various dimensions of innovation, time periods, and regions? Does the impact of TI differ across dissimilar levels of HGD? (3) Does EIA mediate the nexus between TI and HGD? The possible contributions of this study are threefold: (1) the multidimensional comprehensive evaluation index systems of TI and HGD are constructed and calculated to capture the temporal and spatial evolution of TI and HGD, which further enriches the understanding of TI and HGD; (2) this paper not only examines the heterogeneity of TI on HGD from the various dimensions of innovation, time periods, and spatial distribution, but also applies the panel quantile model to investigate the heterogeneous effects across different levels of HGD, which helps us to understand the nexus between TI and HGD from a detailed and comprehensive perspective; and (3) this study not only analyzes the impact of TI on HGD but also examines the mediation effect of EIA, revealing the mediating mechanism of innovation-driven HGD.

2. Literature Review and Hypotheses

2.1. Measurement of TI and HGD. The contemporary research conclusions regarding the nexus between TI and HGD are mixed. One possible reason for these mixed results was that the indicators of variables vary from study to study [16]. Consequently, the selection of core variables for TI and HGD is one of the prominent issues to be addressed in the literature.

Green development has always been one of the areas of focus in academia. There are two main methods for measuring HGD: one method is using total factor productivity [29] or green total factor productivity [1, 8, 13, 14, 16, 26]. Although green total factor productivity is a modification of integrating ecological factors based on total factor productivity, this approach still merely considers the economic efficiency and cannot incorporate the fairness and sustainability of the economy [30]. The second is to build a multidimensional comprehensive assessment system to calculate the HGD index [2, 12], which signifies the comprehensiveness, complexity, and dynamics of HGD. Hence, the multidimensional comprehensive assessment approach is more effective than the total factor productivity method for calculating HGD.

Previous studies select different proxies of TI, and most of them use a single indicator to measure it. Each proxy index provides a particular aspect of TI, but few scholars have combined these indicators to design a multidimensional evaluation system, and then explored the innovation-driven effects. In fact, TI is a value chain [16] and a complex collective process [31]. The innovation input was upstream of the value chain, providing primitive human, material, and financial resources [8]. Innovation output and diffusion are located downstream of the value chain, including the generation of patents and new products, technology diffusion, and technology transfer [32]. In particular, the most commonly adopted indicator of the input dimension was the

intensity of R&D expenditure [1, 24, 25]. The indicators used to characterize the output dimension were patents and new products [11, 16]. Scholars usually divide patents into patent applications [8, 22] and patent grants [23, 26, 27], but the most frequently used indicator of innovation output is patent grants [21, 23, 33]. Early studies expressed innovation diffusion using technical market turnover, and domestic and foreign technological acquisition expenditures [1, 28, 29]. The innovation environment is also an essential determinant of innovation ability, and scholars have utilized government expenditure, human capital, cultural resources, and innovation facilities as proxies for the innovation environment [28, 34, 35].

2.2. The Direct Effect Mechanism of TI on HGD. The endogenous growth theory maintains that TI is the key driving force of productivity growth [36]. Considering a triple dividend from economic growth, HGD simultaneously integrated the efficiency, equity, and green development concepts. In recent years, studies on high-quality economic development and HGD have received increasing attention from scholars. Prior studies separately indicated that TI improved productivity [1], promoted the equity of economic development [37], played a crucial role in reducing pollution emissions, and helped to achieve energy conservation [38]. Therefore, TI has a positive effect on HGD [8, 26, 29]. However, some studies found that TI had a negative effect [22], and several authors discovered that there was a *U*-shaped/inverted *U*-shaped relationship, a threshold effect between TI and HGD [1, 8, 33], or TI promoted HGD depending on the level of other factors [20, 25, 29]. Moreover, TI might have heterogeneous effects on HGD. However, there have been systematically few studies on the impact of heterogeneities, and the relevant research mainly focused on the different effects of the traditional three divisions of the east, middle, and west in China [1, 5, 25], and even fewer studies using panel quantiles [27]. Based on the above literature review, Hypotheses 1 and 2 were proposed.

Hypothesis 1. (H1). TI has a positive effect on the regional HGD.

Hypothesis 2. (H2). TI not only has heterogeneous effects on HGD under different single dimensions of TI, periods, and regions but also has different impacts across the various levels of HGD.

2.3. The Indirect Mechanism of TI Affecting Regional HGD through EIA. TI promotes regional HGD by driving EIA. First, innovation was the core driving force for the development of emerging industries [28]. The ground-breaking results produced by TI were conducive to promoting industrial restructuring and upgrading, which stimulated the emergence of new industries with high-tech content, resource-saving and intensive information, environmental protection, new energy, and new materials and improved the development of a green economy [39]. Second, technological changes facilitated the collaborative agglomeration and

integrated development of emerging industries, resulting in knowledge spillover effects. TI then promoted the realization of the convenience, intelligence, and urbanization of residents' green lives [1], such as education, medical care, and living conditions, through cloud services, big data, and artificial intelligence. Finally, TI promoted the evolution of traditional industries to high value-added products, reducing the emission of pollutants and contributing to the development of a better ecological environment for clean waters and green mountains [38, 40]. Based on the above analysis, this article proposes Hypothesis 3.

Hypothesis 3. (H3). EIA has a mediating effect on the relationship between TI and HGD.

Based on the above Hypotheses (2) and (3), the influence mechanism and transmission path of TI and EIA on HGD are depicted in Figure 1.

3. Data, Variables, and Methodology

3.1. Study Area. The western Yangtze River Delta (YRD), called Anhui Province, is situated in the central mainland of China (see Figure 2). Anhui, which comprises sixteen prefecture-level cities, is an important region and belongs to two national strategic policies. One is the part of the prominent YRD, one of the most developed urban agglomerations in China [41]; the other is one province of the rising of central China strategy. The two national strategies make the multiplier effect of the superposition in the western YRD. The construction practice of "Three Places and One Zone," an essential regional strategic plan, is proposed to promote high-quality economic growth in the western YRD. Under the context of the construction practice "Three Places and One Zone" in the western YRD, this study attempts to incorporate the three variables into a unified analysis framework from a quantitative empirical perspective, guiding for the practical development of the western YRD and a reference sample for relevant developing regions to promote high-quality economic growth.

In addition, to examine the regional heterogeneity, this study divides the research area into two parts. One is the eight cities in Wanjiang City Belt (see Figure 2(c) within the red boundary), and the other is the remaining eight cities. The Wanjiang City Belt, the Anhui section of the Yangtze River, consists of 8 cities along the west of the YRD. In 2010, the State Council approved the construction of the Wanjiang City Belt to undertake an industrial transfer demonstration zone, which is a national industrial transfer development strategy to promote the development of eight cities in the western YRD.

3.2. Econometric Models

3.2.1. The Panel Static Regression Model. Inspired by previous studies [3, 15], this study sets up the following baseline panel regression model based on Hypothesis 1 to empirically estimate the impact of TI on regional HGD as follows:

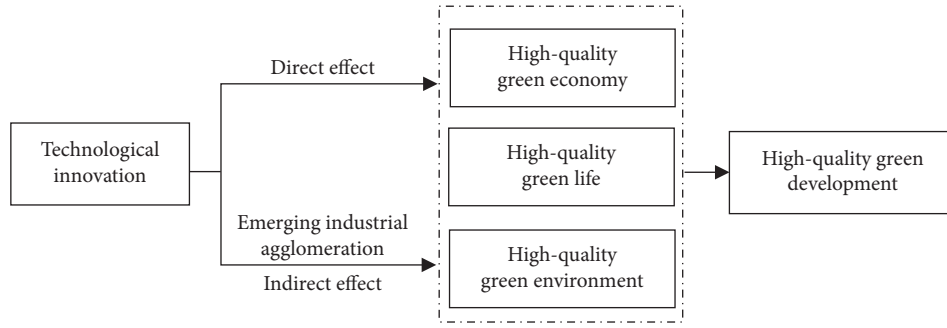


FIGURE 1: The influence mechanism of TI on regional HGD.

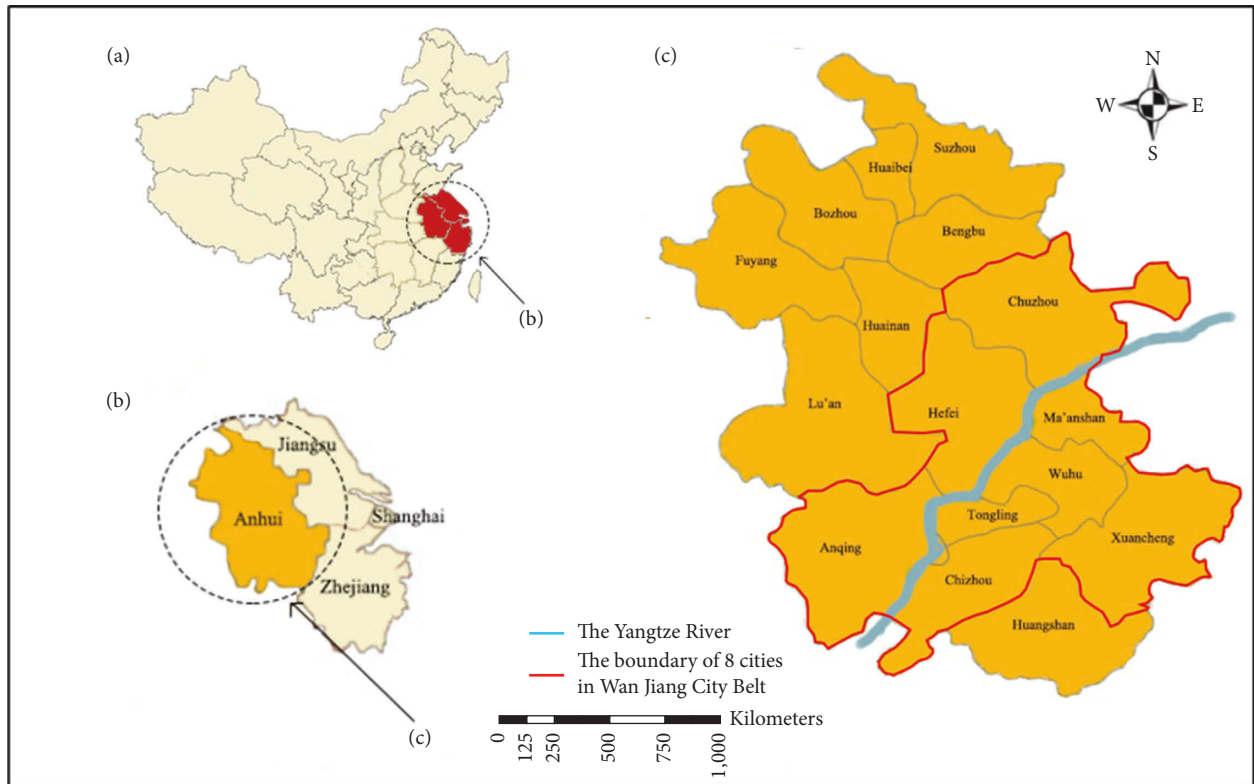


FIGURE 2: Location of the western YRD region, China. (a) China; (b) the YRD region; and (c) Anhui province.

$$HGD = \alpha_0 + \alpha_1 TI_{it} + \alpha_2 control_{it} + \mu_i + v_t + \varepsilon_{it}. \quad (1)$$

In equation (1), HGD represents the explained variable. TI denotes the core explanatory variable; i refers to the city; t is the year, control variables are fiscal, is, den, inf, traf, fina; μ_i and v_t denote the fixed effects of the city and the year, respectively; and ε_{it} is the random disturbance term.

3.2.2. The Panel Interactive Effect Model. The above panel model only reflects the cumulative effects of cities and years, which cannot consider the differences in the effects of common factors on different cities. Therefore, we further construct the panel interactive effect model as [42]

$$HGD = \alpha_0 + \alpha_1 TI_{it} + \alpha_2 control_{it} + \mu_i + v_t + \varepsilon_{it} + \lambda'_i \eta_t + \gamma_{it}, \quad (2)$$

where λ_i refers to the factor loading vector, η_t denotes the unobservable common factor, $\lambda'_i \eta_t$ is the interaction term, and γ_{it} is the random error term.

3.2.3. The Panel Dynamic Model. To solve the problem of endogeneity and robustness, we lag the variable of HGD by one period, denoted as HGD_{it-1} , to construct the dynamic panel data model as [16, 19]

$$HGD = \alpha_0 + \alpha_1 TI_{it} + \alpha_2 HGD_{it-1} + \alpha_3 control_{it} + \mu_i + v_t + \varepsilon_{it}. \quad (3)$$

3.2.4. The Panel Quantile Model. Because the panel quantile estimation results can help us obtain more detailed

TABLE 1: Evaluation index system of regional TI.

Target layer	Index layer	Index description	Property
TI-input (A_1)	B_1 : The intensity of R&D spending (%)	R&D investment intensity	+
	B_2 : The proportion of basic research expenditure in R&D expenditure (%)	R&D investment structure	+
	B_3 : The number of three patent applications granted per 10,000 people (items)	The number of patents granted	+
TI-output (A_2)	B_4 : Ratio of new product sales revenue to main business revenue (%)	New products' revenue	+
TI-diffusion (A_3)	B_5 : Per capita expenditure on technical transformation (yuan)	Technology diffusion cost	+
	B_6 : Ratio of science and technology investment in government expenditure (%)	The government fiscal support	+
TI-environment (A_4)	B_7 : Library books per 100 people (volumes/100 people)	The local cultural environment	+

information, we further conduct the following panel quantile regression analysis as follows [27, 43]:

$$Q_{\text{HGD}}(\tau|x) = \alpha_0 + \alpha_1 TI_{it} + \alpha_2 \text{control}_{it} + \mu_i + v_t + \varepsilon_{it}. \quad (4)$$

In equation (4), Q_{HGD} denotes the conditional quantile function of HGD, and τ expresses the different quantiles.

3.2.5. Mediating Effect Model. According to the analysis of the previous theoretical mechanism, TI may affect regional HGD through EIA. We adopt the panel two-way fixed-effect framework and use the stepwise test regression coefficient method of Baron and Kenny [44] for

$$\text{HGD} = \alpha_0 + cTI_{it} + \alpha_1 \text{control}_{it} + \mu_i + v_t + \varepsilon_{it}, \quad (5)$$

$$\text{EIA} = \alpha_0 + aTI_{it} + \alpha_1 \text{control}_{it} + \mu_i + v_t + \varepsilon_{it}, \quad (6)$$

$$\text{HGD} = \alpha_0 + c'TI_{it} + b\text{EIA}_{it} + \alpha_1 \text{control}_{it} + \mu_i + v_t + \varepsilon_{it}. \quad (7)$$

3.3. Variable Selection

3.3.1. Explanatory Variables

- (1) The core explanatory variable is the composite multidimensional index of TI (TI-total). TI-total in this paper is a complicated process made up of three phases: innovation input-innovation output-innovation diffusion, whose process needs the support of the innovation environment. Inspired by the innovation value chain theory and drawing on the relevant literature, an evaluation index system including seven indicators is constructed to represent the level of TI-total, as listed in Table 1. These seven indicators reflect the levels of cities' TI from four dimensions: innovation input, output, diffusion, and environment. We use the entropy weight method to measure regional TI-total capability by synthesizing one index as a proxy variable, which is subsequently applied to calculate HGD, and single dimensions of the TI index in our study.
- (2) The other four explanatory variables are four single-dimensional indices of TI, namely, innovation input

(TI-in), innovation output (TI-out), innovation diffusion (TI-diff), and innovation environment (TI-envi).

3.3.2. Explained Variable. The explained [8, 26] variable [11, 28, 34, 45, 46] in our [16, 20, 47] study is HGD. Based on the three pillars of sustainable development [5, 48], under the "17 sustainable development goals and 169 targets" action framework of the "2030 Agenda for Sustainable Development" [49], we establish the HGD evaluation index system, made up of 18 indicators from the three dimensions of high-quality green economy, green life, and green environment, and shown in Table 2. Among them, the high-quality green economy dimension is expressed by four aspects, namely, the quantity of economic growth (D_1 and D_2) [2, 5, 12, 15, 21, 50], economic efficiency (D_3 and D_4) [12, 50], economic sustainability (D_5) [12, 15, 50], and economic stability (D_6) [2, 50]. The high-quality green life dimension mainly considers the equity of economic development, covering education (D_7) [2], health care (D_8) [2], service for the aged (D_9) [2], living condition (D_{10}) [2], income gap (D_{11}) [2], and taking environmentally friendly modes of transportation (D_{12}) [2, 50]. The high-quality green environment dimension considers the gases, liquids, and solids of industrial pollution emissions (D_{13} , D_{14} , and D_{15}) [2, 12, 50], and air quality (D_{16}) [50], green area (D_{17}) [2, 50], and the amount of applied fertilizer application (D_{18}) [50].

3.3.3. Mediating Variable. The mediating variable of this study is EIA. As emerging industries are more closely related to TI than other industries, and EIA is a strategic plan that China has attached great importance to promoting HGD in recent years, this study takes EIA as the mediating variable rather than industrial agglomeration. The location quotient index is widely applied by economists and economic geographers as an accurate method to reflect the spatial distribution of various regional elements, which can eliminate the deviation caused by uneven regional scales [51, 52]. Consequently, we choose the location quotient index constructed by emerging industry personnel covering three types of employees in the information transmission industry, computer service industry, and software industry as the proxy variable for EIA [53]. The calculation formula is as follows:

TABLE 2: Evaluation index system of regional HGD.

Dimensions	Code: criteria	Property
High-quality green economy (C_1)	D_1 : Per capita GDP (yuan/person)	+
	D_2 : Per land GDP (yuan/hm ²)	+
	D_3 : Land yield efficiency of secondary industry (yuan/m ²)	+
	D_4 : Labor productivity in tertiary industry (10,000 yuan/person)	+
	D_5 : Energy consumption per unit of GDP (a ton of standard coal/10,000 yuan)	-
	D_6 : Registered urban unemployment rate (%)	-
High-quality green life (C_2)	D_7 : Ratio of education expenditure in government finance expenditure (%)	+
	D_8 : Number of beds in medical institutions per 1,000 people (beds)	+
	D_9 : Ratio of people with primary old-age insurance in those aged 15 years and above (%)	+
	D_{10} : Per capita housing floor area (m ²)	+
	D_{11} : Per capita disposable income between urban and rural residents (yuan)	-
High-quality green environment (C_3)	D_{12} : Number of public transport vehicles per 10,000 people (unit)	+
	D_{13} : Total industrial exhaust emissions (100 million standard/m ³)	+
	D_{14} : Total discharge of industrial wastewater (10,000 tons)	+
	D_{15} : Production of industrial solid waste (10,000 tons)	-
	D_{16} : Proportion of weather with air quality reaching or better than grade 2 (%)	-
	D_{17} : Park green area per capita (m ² /person)	-
	D_{18} : Fertilizer application amount per unit cultivated area (kg/hm ²)	-

$$EIA = \left(\frac{f_{ii}/F_I}{f_i/F} \right). \quad (8)$$

In equation (8), f_{ii} represents the number of employees in the above three industries in the i prefecture-level city; F_I signifies the total number of employees in the above three industries; f_i is the number of employees in the i prefecture-level city; and F reflects the total number of employees.

3.3.4. Control Variables. As the regional HGD is affected by many factors, to reduce the bias caused by the omitted variables, six control variables are introduced in our model: (1) fiscal level (fiscal): taking into account the crucial role of promotion and support for the government in the development of TI, and the close relations between fiscal revenue and HGD [20], this paper uses the ratio of local government fiscal revenue to GDP in the various cities to measure the level of regional fiscal revenue. (2) Industrial structure (is): in line with the previous study [54], this study selects an indicator reflecting the degree of advanced industrial structure, namely, the ratio of the output values of the tertiary and secondary industries to represent the industry structure. (3) Population size (den): we use the population density of various cities to express the regional population size [20]. (4) Informatization level (inf): given the close connection between TI and information infrastructure [55], we choose the number of broadband internet users to reflect the level of informatization. (5) Infrastructural level (traf): it is denoted as per capita urban road area. (6) Financial level (fina): we measure the financial level by the ratio of the balance of various loans to GDP [8].

3.4. Data Source. The raw data were retrieved from “China City Statistical Yearbook (2010–2020),” “China Science and Technology Statistical Yearbook (2010–2020),” “Anhui Province Statistical Yearbook (2010–2020),” the various

prefectural statistical yearbooks (2010–2020), and the Chinese WIND database. To eliminate the heteroscedasticity as much as possible and refrain from the regression bias by the different dimensions of the indicators, logarithmic processing was conducted on the variables. Table 3 reports the results of descriptive statistics.

This article selects 2009–2019 as the research period for the following reasons. First, since 2009, with the impact of the global economic crisis, the Chinese government attached more importance to the innovation and high-quality economic development strategies of the western YRD. Second, a series of guiding plans were proposed to promote the integrated construction of the YRD during 2009–2019. Third, China formally proposed the concept of emerging industries in 2009 and then successively introduced a series of policies for EIA.

4. Results and Discussion

In this paper, the data are processed as follows before the panel regression analysis to ensure the validity of the model estimation: (1) to avoid the problem of multicollinearity, the independent variables, control variables, and the mediating variables in the model are checked by the variance inflation factor (VIF). Because the test result of VIF is 2.23, there is no obvious multicollinearity problem. (2) As the modeling process of stationary and nonstationary data significantly varies, this paper conducts a panel unit root test to avoid spurious regression problems. Three testing approaches are employed to ensure robustness: the LLC test, IPS test, and ADF test. All variables passed the significance tests, and it is feasible to examine the panel data models.

4.1. Baseline Panel Regression Analysis of the Multidimensional TI Index on HGD. This study first verifies the TI index of the total dimensions (TI-total index) affecting HGD. To ensure the effectiveness of the panel regression model, various estimation models are used for analysis, and all

TABLE 3: Variable definition and descriptive statistics.

Variable symbol	Variable classification	Variable declaration	N	Min	Max	Mean	S.D.
HGD	Explained variable	HGD index	176	0.122	0.719	0.369	0.159
TI-total	Core explanatory variable	TI-total index	176	0.017	0.934	0.259	0.209
TI-in	Explanatory variable	TI-input index	176	0.009	1.000	0.299	0.239
TI-out	Explanatory variable	TI-output index	176	0.000	1.000	0.307	0.259
TI-diff	Explanatory variable	TI-diffusion index	176	0.000	1.000	0.174	0.272
TI-envi	Explanatory variable	TI-environment index	176	0.000	0.936	0.267	0.244
EIA	Mediating variable	Emerging industrial agglomeration	176	0.230	4.544	1.016	0.792
fiscal	Control variable	Fiscal revenue	176	0.010	2.646	1.747	0.551
is	Control variable	Industrial structure	176	3.443	5.118	4.319	0.352
den	Control variable	Population size	176	6.372	8.587	7.806	0.489
Inf	Control variable	Informatization level	176	1.943	5.854	3.704	0.787
Traf	Control variable	Infrastructural level	176	0.698	3.774	2.508	0.588
fina	Control variable	Financial development	176	2.114	3.104	2.538	0.221

TABLE 4: Regression results of the impact of TI-total index on regional HGD.

	(1) OLS	(2) FE	(3) RE	(4) Two-way FE	(5) INFE	(6) PCSE
TI-total	0.675*** (0.044)	0.201*** (0.041)	0.401*** (0.034)	0.176** (0.044)	0.175*** (0.038)	0.176** (0.056)
lnfiscal	0.051*** (0.009)	0.027** (0.007)	0.028*** (0.006)	0.021** (0.009)	0.018** (0.009)	0.021** (0.008)
lnis	0.040 (0.027)	0.057** (0.024)	0.044** (0.019)	-0.055 (0.037)	-0.093** (0.030)	-0.055 (0.035)
lnden	0.017 (0.025)	0.009 (0.019)	0.012 (0.021)	-0.000 (0.012)	0.010 (0.016)	-0.000 (0.020)
lninf	-0.050** (0.017)	-0.026** (0.011)	-0.030** (0.011)	-0.028 (0.018)	-0.018 (0.020)	-0.028 (0.020)
lntraf	0.005 (0.020)	-0.001 (0.012)	0.008 (0.013)	-0.025** (0.009)	-0.036** (0.014)	-0.025** (0.011)
lnfina	-0.088** (0.030)	-0.036 (0.019)	-0.052** (0.020)	0.028 (0.032)	0.029 (0.033)	0.028 (0.026)
City-fixed effects	—	YES	—	YES	YES	YES
Year-fixed effects	—	—	—	YES	YES	YES
Cons	0.195 (0.238)	0.146 (0.218)	0.161 (0.234)	0.608** (0.260)	0.703** (0.226)	0.508** (0.238)
N	176	176	176	176	176	176
R ²	0.866	0.225	0.860	0.407	0.027	0.968

Note: robust standard errors are in all parentheses. The symbols *, **, and *** denote significance at the levels of 10%, 5%, and 1%, respectively; the same for the following tables.

models are represented by robust standard errors to avoid heteroscedasticity. Table 4 compiles the results. In this paper, the traditional three-panel regression models (namely, mixed effects, fixed, and random effects) are examined, as shown in columns (1)–(3). After the Hausman test, $\chi^2(7) = 58.75$, $\text{Prob} > \chi^2 = 0.0000$; therefore, it is appropriate to choose the fixed-effect model. Column 4 reports the estimation results for the two-way fixed-effect model, in which the city and year are both fixed. Based on the fixed city and year, column 5 introduces the interaction terms of the two to construct a panel interaction fixed-effect model. To address the problem of heteroscedasticity, cross-sectional autocorrelation, and intragroup autocorrelation on the regression results, the calibration standard error estimation method is analyzed and presented in column 6. Regardless of which estimation model is adopted, the coefficient of TI-total is significantly positive, which strongly proves that TI

promotes HGD. Hypothesis 1 is strongly confirmed. These findings are consistent with the research conclusions of Cheng et al. [27] and Huang et al. [29], indicating that TI is an important driving force for regional HGD, because innovation is not only an effective way to increase productivity, but also one of the breakthrough dimensions to promote the sharing of social results and achieve green development.

Model 4, two-way fixed-effect model, is selected to discuss the estimation results. TI has a positive effect on HGD at the 5% significance level, indicating that for every unit increase per unit of the TI-total index, the regional HGD increases by 0.176 units. In terms of control variables, the regional fiscal revenue level has a positive impact on HGD, while the infrastructural level has a negative impact on HGD. Additionally, the industrial structure, population size, informatization level, and financial development level have not passed the significance test.

TABLE 5: The impact of different single dimensions of TI on regional HGD.

	(1) Two-way FE		(2) INFE	
	No control variables	Control variables	No control variables	Control variables
TI-in	0.017 (0.032)	0.028 (0.026)	0.056 (0.033)	0.052 (0.032)
TI-out	0.119** (0.030)	0.121*** (0.024)	0.120*** (0.028)	0.100*** (0.029)
TI-diff	0.050** (0.023)	0.062** (0.017)	0.064*** (0.019)	0.055** (0.018)
TI-envi	0.104 (0.051)	0.076 (0.048)	0.048 (0.035)	0.045 (0.035)
City-fixed effects	YES	YES	YES	YES
Year-fixed effects	YES	YES	YES	YES
<i>N</i>	176	176	176	176

4.2. Analysis of Heterogeneous Effects. We have investigated the baseline regression between TI and HGD. Now we consider the possible heterogeneous effects in relation to various single dimensions of TI, temporal difference, and spatial distribution, which may tell us more interesting stories.

4.2.1. Different Single Dimensions of TI. This study examined whether the four single dimensions of TI affect HGD. Given that the two-way fixed-effect model and the interaction effect model are more effective for this sample, this section only reports the regression results of these two models, as shown in Table 5. Models (1) and (2) are the two-way fixed-effect model and panel interactive fixed-effect model, respectively. In addition, each model is estimated under scenarios of no control variables and six additional control variables.

Table 5 shows that the four single dimensions of TI have a heterogeneous impact on HGD. Regardless of whether the control variables are considered, the coefficients of innovation output and innovation diffusion are both positive at the 1% and 5% levels of significance, respectively. In contrast, the coefficients of innovation input and innovation environment fail to pass the significance test. Compared with the prior study [25], this article provides the evidence that TI is a multidimensional and dynamic concept, and innovation output and diffusion are direct innovation activities, which have a more direct and influential effect on HGD compared with innovation input and the environment, while innovation input and the innovation environment may indirectly promote HGD through innovation output and diffusion [8, 56].

4.2.2. Temporal and Spatial Heterogeneities. Given the adverse effects of severe haze pollution on the development of regional HGD in recent years, and the 2013 “Ten Atmosphere policies” put forward control requirements for PM_{2.5} and PM₁₀ emissions from prefecture-level cities, we divide the analysis period into two stages to conduct the temporal heterogeneity analysis. Furthermore, we classify the sample data into two sections, eight cities in the Wanjiang City Belt (as shown in Figure 2(c)) and eight cities in the non-

Wanjiang City Belt, to explore the spatial heterogeneity. Table 6 displays both the temporal and spatial heterogeneities. Temporal heterogeneity analysis indicates that the estimation coefficients for the two time periods are both significantly positive, but the coefficient value for 2014–2019 (0.186) is greater than that for 2009–2013 (0.144), which suggests that the innovation-driven effect during 2014–2019 is stronger than that during 2009–2013. The results of spatial heterogeneity reveal that the impacts of TI on HGD present different characteristics in the two kinds of regions. The promotion effects of TI on HGD are evident in the eight cities of Wanjiang, but TI has negligible impacts on the area of eight cities of non-Wanjiang; thus, Hypothesis 2 is verified. This finding proves that the promulgation of the “Ten Atmosphere policies” might promote the effect of innovation-driven HGD. Although sixteen cities have been all incorporated into the integrated development plan of the YRD, there are still differences in the innovation-driven effect between cities along the Yangtze River and those not along the river.

4.3. Results of Panel Quantile Regression. Given the partial absence of the baseline regression results of the mean analysis, considering the differences in the sensitivity of different HGD levels to innovation, the study uses the quantile econometric model to obtain the in-depth and detailed information and heterogeneous effects of TI on HGD. Nine quantiles of 0.1, 0.2, 0.3, ..., 0.9 are selected in turn to examine the different effects. Table 7 reports the results.

The results based on two-way fixed-effect panel quantile estimation show that the estimated coefficients of the core explanatory variables at different quantile points significantly vary. This finding indicates that the mean effect makes it difficult to comprehensively explain the comprehensive economic situation, and it is useful to perform the panel quantile regression. In particular, the coefficients of TI-total are significant and positive except for the 10th quantile, and the coefficients gradually increase as quantiles move from low to high, which further proves that TI can effectively promote HGD. The higher the level of HGD is, the greater the contribution of TI to HGD. This finding may be because in cities with a higher level of HGD, the improvement of

TABLE 6: The impact of TI on regional HGD under spatiotemporal differences.

	Temporal heterogeneity		Spatial heterogeneity	
	2009–2013	2014–2019	Cities in Wan Jiang City Belt	Cities in non-Wan Jiang City Belt
TI-total	0.144** (0.066)	0.186** (0.049)	0.228*** (0.030)	0.038 (0.123)
Control variable	YES	YES	YES	YES
City-fixed effects	YES	YES	YES	YES
Year-fixed effects	YES	YES	YES	YES
<i>N</i>	80	96	88	88
<i>R</i> ²	0.454	0.431	0.508	0.459

TABLE 7: Quantile regression results of TI on regional HGD.

τ quantiles	$\tau = 0.1$	$\tau = 0.2$	$\tau = 0.3$	$\tau = 0.4$	$\tau = 0.5$
TI-total	0.156 (0.106)	0.171** (0.081)	0.182** (0.066)	0.196*** (0.053)	0.205*** (0.051)
Control variable	YES	YES	YES	YES	YES
City-fixed effects	YES	YES	YES	YES	YES
Year-fixed effects	YES	YES	YES	YES	YES
$\tau\tau$ quantiles	$\tau = 0.6$	$\tau = 0.7$	$\tau = 0.8$	$\tau = 0.9$	
TI-total	0.214*** (0.054)	0.221*** (0.061)	0.231** (0.073)	0.241** (0.088)	
Control variable	YES	YES	YES	YES	
City-fixed effects	YES	YES	YES	YES	
Year-fixed effects	YES	YES	YES	YES	

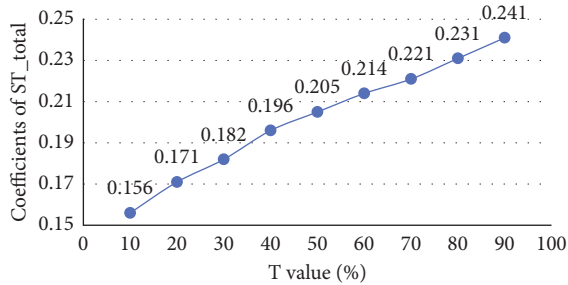


FIGURE 3: The variation of panel quantile regression coefficients for TI-total.

production efficiency by technological progress is higher than that in cities with lower levels. The results regarding quantile differences confirm the theory of the innovation paradox. The return from the innovation activities of lower development regions is lower than that of higher ones [57].

To give a clearer economic interpretation of the panel quantile regression, we draw the graph of the coefficient variations of different quantiles of the core explanatory variable, as illustrated in Figure 3. From the perspective of the coefficient significance, at the 10th quantile, the coefficient fails to pass the significance test, and the rest of the quantiles are significant. From the perspective of the coefficient value, all coefficients are positive and gradually increase as the quantile shifts to the right, indicating that the role of TI in promoting regional HGD is gradually increasing. That is, the higher the level of HGD is, the more obvious the driving effect of TI. Hypothesis 2 is also tested. Therefore, we not only focus on mean effects to decompose the TI into four dimensions to investigate the effects of TI-

TABLE 8: Dynamic panel regression results of TI on regional HGD.

	System GMM	
	One step	Two steps
L.HGD	0.558*** (0.107)	0.494** (0.155)
TI-total	0.324*** (0.063)	0.567** (0.173)
Control variable	YES	YES
AR (1)	0.010	0.061
AR (2)	0.566	0.445
Hansen test	1.000	1.000
<i>N</i>	160	160

Note: AR (1), AR (2), and the Hansen test are *P* values.

total index and TI four dimensions on regional HGD, respectively, but also adopt a panel quantile framework to explore TI across the conditional distribution of HGD. Such investigation will assist us in understanding the effects of TI on HGD.

4.4. Analysis of Endogenous Issues. This paper uses control variables as much as possible to reduce the influence caused by the omitted variables. The two-way fixed-effect model allows the regional effect to be related to the explanatory variables, which can overcome the endogenous problem caused by the omitted variables to a certain extent. However, due to the possible simultaneous causality between core dependent and independent variables, there might be a reverse nexus between TI and HGD, whereby HGD might have an impact on TI. Therefore, we then lagged the explained variable by one period as an instrumental variable

TABLE 9: Results of the mediating effect of EIA on the relationship between TI and HGD.

Variables	(1) HGD	(2) EIA	(3) HGD
TI-total	0.176** (0.044)	2.118** (0.894)	0.126** (0.036)
EIA			0.024*** (0.005)
Control variable	YES	YES	YES
City-fixed effects	YES	YES	YES
Year-fixed effects	YES	YES	YES
N	176	176	176
R^2	0.407	0.368	0.433

TABLE 10: Robustness check for baseline regression.

	(1) TI-PHGD	(2) ST-HGD	(3) TI-HGD	(4) TI-HGD
TI-total/ST	0.142*** (0.025)	0.177*** (0.037)	0.174*** (0.042)	0.179** (0.048)
Infiscal	0.010 (0.008)	0.021** (0.009)	0.022** (0.009)	0.021** (0.008)
Inis	-0.052 (0.036)	-0.055 (0.034)	-0.057 (0.033)	-0.053 (0.037)
Inden	0.012 (0.013)	0.002 (0.011)	0.000 (0.012)	-0.000 (0.012)
lninf/er	-0.018 (0.015)	-0.026 (0.018)	0.029 (0.020)	-0.027 (0.018)
Intraf	-0.017 (0.011)	-0.031** (0.008)	-0.032** (0.008)	-0.025** (0.009)
Infina	0.026 (0.034)	0.051 (0.029)	0.021 (0.033)	0.029 (0.033)
City-fixed effects	YES	YES	YES	YES
Year-fixed effects	YES	YES	YES	YES
Constant	0.480 (0.254)	0.541** (0.212)	0.443 (0.252)	0.593** (0.260)
N	176	176	176	176
R^2	0.384	0.443	0.408	0.403

to alleviate the endogeneity issue. Since the system GMM is more effective than the difference GMM [16, 19], the `xtabond2` command of Stata 15.0 software is used to conduct the analysis of the one-stage and two-stage system- GMM dynamic panel models [58], as listed in Table 8. The coefficients of the core explanatory variables and the first-order lag are significantly positive, which addresses the endogenous issue to a certain extent, and the empirical results are reliable.

4.5. Mediating Effect of EIA. Earlier in this paper, the transmission mechanism of TI on regional HGD from the perspective of EIA was theoretically analyzed. To verify this dual path, the panel mediation effect model with the stepwise regression method is selected for investigation, and the results are demonstrated in Table 9. Model (1) is used to examine whether TI promotes HGD, and model (2) signifies whether TI has a positive effect on EIA. The regression coefficients of TI in the above two models are both significantly positive. Finally, EIA, the mediating variable, is added to the baseline regression. The coefficient of TI in model (3) is also significantly positive and lower than that in model (1), indicating that EIA mediates the relationship between TI and HGD. Thus, Hypothesis 3 is supported.

In particular, the total effect of TI on regional HGD is 0.176, in which the direct effect is 0.126, accounting for almost 71% of the total effect, and the indirect effect is 0.051, accounting for approximately 29% [44]. Therefore, the causal chain of TI affecting the regional HGD through EIA is confirmed.

4.6. Robustness Check. To ensure the consistency and stability of the estimation results, Table 10 shows the results of robustness tests on the empirical analysis from the following aspects. (1) *Replacing the Measurement of HGD.* Through different constituent indicators and weights, the HGD index is recalculated and expressed as PHGD. The results signify that the direction of the coefficient of TI-total is unchanged and significant, as shown in column 1. (2) *Replacing the Measurement of TI.* We adopt the same method as in robustness check (1), replacing the key explanatory variable, denoted as ST. The results also disclose that the regression coefficient is significantly positive, as listed in column 2. (3) *Changing the Control Variables.* We replace the informatization level variable with the environmental regulation, represented by `er`, and the results are still stable, as demonstrated in column 3. (4) *Applying Different Regression Models.* This paper applies seven different regression models

TABLE 11: Robustness check for the mediating effect.

Variables	(1) Replacing the independent variable			(2) Tailoring treatment		
	HGD	EIA	HGD	HGD	EIA	HGD
TI-total/ST	0.177*** (0.037)	1.678** (0.711)	0.143** (0.035)	0.179** (0.048)	2.099** (0.939)	0.127** (0.037)
EIA			0.020** (0.005)			0.025*** (0.004)
Control variable	YES	YES	YES	YES	YES	YES
City-fixed effects	YES	YES	YES	YES	YES	YES
Year-fixed effects	YES	YES	YES	YES	YES	YES
<i>N</i>	176	176	176	176	176	176
<i>R</i> ²	0.443	0.354	0.462	0.403	0.357	0.432

for the analysis. The coefficients of the key explanatory variables are consistent. (5) *Tailoring Treatment*. Considering the possible impact of extreme samples on the results, the core explanatory variable and the explained variable are reduced by 1% up and down. The regression coefficient of TI-total does not significantly deviate from the estimated results, providing evidence to confirm the validity of the above findings, and is depicted in column 4.

Moreover, the mediation effect has also been appraised for robustness. By replacing the independent variable and tailoring treatment, the direction of the core explanatory variable coefficient remains unchanged and is significant, which confirms the robustness of the conclusions. The results of the robustness test are presented in Table 11.

5. Conclusions and Recommendations

5.1. Conclusions. Based on the construction practice of “Three Places and One Zone” in western YRD, this article provides a detailed investigation by incorporating new variables, EIA, to explore the traditional TI-economic growth nexus. Using panel data from 2009 to 2019 in the western YRD of China, this study examines the heterogeneous effects in terms of various single dimensions of TI, periods, regions, and different levels of HGD, and then investigates the relationship among TI, EIA, and HGD. Such exploration extends the current research by identifying comprehensive indicators for variables and may provide a development sample of high-quality economic growth in related developing regions. Conclusions are summarized as follows.

First, TI is a crucial factor in promoting HGD in the western YRD of China. For the composite index, TI significantly promotes HGD. This finding shows that the innovation-driven development strategy that the Chinese government has been pursuing has important practical guiding significance.

Second, TI has heterogeneous impacts on HGD at different dimensions of innovation, time periods, regions, and various HGD levels. (1) For the single dimensions of TI, innovation input and innovation environment are not evident in promoting HGD, while innovation output and innovation diffusion have a significant impact on HGD. Therefore, four different dimensions of TI have heterogeneous impacts on HGD. While exploring the nexus between innovation and economy, more innovation output and diffusion indicators

need to be concerned. (2) The innovation-driven HGD in the Wanjiang City Belt has a positive effect, while the non-Wanjiang have an insignificant effect. In addition, the nexus between TI and HGD also significantly differs before and after 2013. (3) As the HGD index moves from the low quantile to the high quantile, the driving role of TI gradually increases. Hence, it is necessary to develop differentiated policies according to various HGD levels.

Third, the result of the influence mechanism shows that EIA mediates the nexus between TI and HGD. The outcomes show that TI empowers regional HGD by enhancing EIA, and the indirect effect of EIA is lower than the direct effect. This finding further supplements the existing research on the mediation effect of industrial development. Therefore, TI not only directly promotes HGD but also indirectly promotes HGD through EIA. While vigorously developing TI, it is also crucial to strengthen EIA to further accelerate HGD and promote the high-quality economic growth.

Therefore, it can be concluded that the construction practice of “Three Places and One Zone” has great practical significance in promoting regional HGD, thereby achieving high-quality economic development. The outcomes contribute to a detailed understanding of the impact of TI on HGD in China and other developing regions.

5.2. Policy Recommendations. To promote the high-quality economic growth in the western YRD, it is necessary to scientifically manage the relationship between TI, EIA, and HGD. According to the empirical estimations of the results, the policy recommendations are as follows.

First, the government should promote innovation-driven HGD effects. (1) The government should vigorously promote the innovation-driven development strategy, and accelerate the in-depth integration of TI and HGD.

Second, the policy-makers should formulate differentiated regional development plans based on different cities along the river, areas with different HGD levels, subdimensions of TI, and periods. (1) Government should give full play to the supporting role of policies in innovation activities, create a favorable innovation environment, and form an innovation value chain to promote the transformation of innovation investment into innovation outputs and innovation diffusion effects. (2) The eight cities in the Wanjiang City Belt should continue to take advantage of the synergy and interaction of

the urban belt, and the eight non-Wanjiang cities should also actively integrate into the construction of the YRD to accelerate innovation-driven HGD. (3) When formulating innovation-driven strategies, effective policies should be designed based on the different HGD levels, and the regional effect of the innovation paradox should be reversed to improve the innovation-driven effects for the regions with a lower HGD index.

Third, the government should continuously improve the coordinated development of TI and EIA. In the process of high-quality economic development, a single emphasis on TI or EIA has a limited impact on HGD. Therefore, the coordinated development of TI and EIA can better promote HGD, and further promote high-quality economic development. In particular, policy-makers should prioritize emerging industries. On the one hand, the government should expand the upgrading of industrial structure, explore the development path of “technology + emerging industries,” and eliminate some industries with backward technology and overcapacity; on the other hand, it is crucial that policy-makers enhance the positive linkage of industrial function complementation and strengthen regional cooperation and governance to build an EIA community in the YRD.

Our study might be the first investigation that incorporates the three variables, namely, TI, EIA, and HGD, in the same conceptual framework by creating composite indices of TI and HGD. However, there are still some limitations that need further exploration. In future research, based on the four single dimensions of TI, we will continue to study the impact of each indicator of a single dimension on HGD, such as whether patents and new products have heterogeneous effects on HGD. Moreover, due to the limitations of data availability, the study area is confined to the western YRD, and we will expand the sample area to the whole YRD or other urban agglomerations and employ green innovation to empirically analyze the influence mechanism once the data can be obtained.

Data Availability

The datasets generated during and/or analyzed during the current study are available in the China Statistical Bureau, China City Statistical Yearbook (2010–2020), China Science and Technology Statistical Yearbook (2010–2020), and Anhui Province Statistical Yearbook (2010–2020) repository (<https://tjj.ah.gov.cn/>)(accessed on 4 January 2021).

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

J.C. and Z.L. contributed to conceptualization; J.C. and Z.L. contributed to methodology; J.C. and J.X. contributed to investigation; J.C. and M.L. contributed to software; J.C. contributed to writing-original draft; Z.L. contributed to supervision; J.C., J.X., and M.L. contributed to visualization; and J.C. and Z.L. contributed to project administration; J.C.

contributed to funding acquisition. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

Special thanks are due to the mentor and advisor, Dr. Marilyn Rose Lafay, for guidance with the paper. This work has been financially supported by the Philosophy and Social Science Program Youth Project in Anhui Province of China, “Measurement, Comparison, and Strategic Path of High-Quality Green Development in Anhui Province under the Integration Strategy of Yangtze River Delta” (No. AHSKQ2020D31).

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