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RESEARCH ARTICLE

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Green development and economic resilience: Evidence from Chinese resource-based cities

Abstract Resource-based cities are currently facing challenges due to ecological pollution and an unbalanced industrial structure, which hinders sustainable economic growth. The focus on green development as a strategy for economic growth and environmental protection is becoming increasingly popular. This study employs a spatial econometric model to explore the effect of green development on economic resilience in Chinese resource-based cities from 2011 to 2019, revealing a positive correlation between green development and economic resilience. For each 1 unit increase in green development, economic resilience increases by an average of 0.512 units. Furthermore, the analysis of heterogeneity reveals differences in the factors influencing various resource-based cities. In addition, provincial green policies bolster economic resilience by encouraging green development. This research aids in comprehending the balance between the economy and the environment.

Keywords economic resilience, green development, spatial econometric models, resource-based cities.

1 Introduction

Economic systems are complex and adaptive, continually absorbing energy from the external environment and evolving simultaneously. Economic resilience (ER), on the other hand, refers to the capacity of a region's economic system to withstand shocks and pursue a new development path after experiencing an external crisis or internal distress (Wang et al., 2022b). It specifically evaluates cities' ability to recover from shocks, absorb them, and adapt positively (Martin et al., 2016; Duan et al., 2022). The concept of economic resilience has attracted much academic attention when studying regional economies (Hassink, 2010). In particular, the global economy has faced unforeseen crises in recent decades, such as the COVID-19 pandemic and the Russia–Ukraine conflict. ER, as a measure of resistance to external shocks, has gained substantial attention. Policymakers worldwide concur on the need to "build resilient economies" to ensure sustainable economic development (Kass-Hanna et al., 2022).

Resource-based cities are primarily driven by industries such as mining and logging (Li et al., 2023a; Ruan et al., 2020; He et al., 2017), which play a significant role in global development through resource utilization (Chen et al., 2018; Chapman et al., 2015). However, the convergence of economic development and environmental issues has become a topic of extensive debate due to their distinctive production modes (Kummitha, 2019; Hu and Yang, 2019). Nevertheless, current research on economic resilience has focused primarily on industry, policy, finance, and innovation (Tan et al., 2020; Tang et al., 2023; Bristow and Healy, 2018; Wang et al., 2023c; Brown and Greenbaum, 2017), often neglecting a critical aspect of sustainable development, namely, the integration of the environment and economic progress.

Many previous studies have examined the connection between green development and sustainable economic growth from various perspectives, such as green finance, green industry, energy transition, and green innovation (Tariq and Hassan, 2023; He et al., 2023; Lee et al., 2023b; Nenavath and Mishra, 2023). However, these studies often overlook the direct evaluation of the level of green development in cities by considering integrated environmental and economic results. Therefore, the objective of this study is to establish a comprehensive indicator to evaluate the impact of green development on the economic resilience of resource-based cities. The

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measurement system for the level of green development includes multiple dimensions, including economy, environment, and energy (Qin et al., 2023; Xu et al., 2022; Yuan et al., 2023). In particular, green total factor productivity (GTFP), which integrates energy inputs, economic outputs, and environmental pollution (Feng et al., 2019), is utilized to minimize energy consumption and environmental pollution while simultaneously achieving economic growth. Consequently, we aim to provide a more comprehensive reflection of the level of green development through the measurement of GTFP.

Moreover, existing research often neglects the spillover effect between cities when investigating the factors influencing urban economic resilience (Tan et al., 2020; Lei et al., 2023). However, recognizing the importance of spatial influences and interconnectivity among cities (Tobler, 1970), econometric analyses that fail to account for spatial correlations may introduce some bias to the estimation results (Anselin and Griffith, 1988; Ren et al., 2023b). Thus, this study employs spatial econometric modeling.

Consequently, a spatial econometric model is employed to evaluate the association between green development and economic resilience in 113 resource-based cities in China from 2011 to 2019. The indicator used to assess green development in this study was GTFP. The findings of this study reveal a positive correlation between green development and improved economic resilience. Additionally, a heterogeneity analysis is conducted, and the moderating role of provincial green development policies in the relationship between GTFP and economic resilience in prefecture-level cities is explored.

This paper presents several significant contributions to the existing body of knowledge. First, we provide an innovative exploration of the impact of urban green development on economic resilience from the perspective of green economic growth. This research perspective offers a fresh approach to understanding the factors influencing economic resilience, surpassing the previous focus on industrial structure and financial development. Second, our research focuses on resource-based cities, aiming to provide valuable insights to support their pursuit of sustainable economic development. We also propose constructive suggestions to coordinate the development of the environment and economy in these cities. Finally, we examine the moderating role of provincial green development policies in the impact of urban green development on economic resilience. By considering the nested role of provincial-level and prefectural-level cities, our study addresses the lack of literature on policy impact. Furthermore, our findings can inform provincial governments in formulating appropriate policies to promote urban green economic growth.

The following sections of this paper are organized as follows. Section 2 provides a summary of relevant research on green development and economic resilience and establishes research hypotheses. Section 3 outlines the measurement methods of the variables and econometric models employed in our study. Section 4 presents the baseline regressions and robustness tests conducted for this research. Section 5 analyzes the moderating effect mechanism. Finally, Section 6 discusses the key findings and provides policy recommendations.

2 Literature review and research hypothesis

2.1 Economic resilience and green development

The term "resilience" originates from the Greek word "resilire" and was originally used in ecology to signify rebounding or jumping (Holling, 1973; Martin, 2012). It has since been extended to economic and social systems. The ER is commonly defined as a dynamic self-adjusting capacity that includes vulnerability, resistance, redirection, and resilience (Martin et al., 2016). These dimensions represent an economy's ability to withstand external shocks and subsequently recover quickly to its original growth trajectory or establish a new growth path (Boschma, 2015; Corodescu-Roşca et al., 2023). Green development is widely acknowledged as a crucial strategy for addressing urban environmental issues and encouraging sustainable urban economic development (Gazzola et al., 2019; Jin et al., 2023). It includes economic, social, and ecological dimensions, making it a comprehensive development approach. In the current global context, achieving a balance between economic growth and environmental sustainability is increasingly important (Tawiah et al., 2021; Li et al., 2023c; Ren et al., 2023a). Recent studies have shown that green development can foster urban economic growth through technological innovation and the utilization of clean energy (Li et al., 2023b; Zhou et al., 2023; Capasso et al., 2019; Luukkanen et al., 2019). Moreover, green development plays a positive role in sustainable economic development by facilitating the continual development of green finance, infrastructure, and environmental protection (Ouyang et al., 2023; Zhang and Dilanchiev, 2022; Wang et al., 2023a; Tariq and Hassan, 2023).

Additionally, the "resource curse" theory suggests a positive correlation between green development and economic resilience. This theory highlights the challenge faced by resource-rich regions or countries in effectively utilizing their resources to stimulate economic growth, sometimes hindering sustainable economic development (Auty, 1994). Analysis reveals that one of the key factors contributing to the "resource curse" is the crowding-out effect experienced by resource-based cities (Wang et al., 2022a; Wang et al., 2023d). These cities exhibit a lower demand for research and development (R&D) activities, innovation, and high-skilled labor, subsequently hampering innovation and employment opportunities (Cheng et al., 2020a; Cheng et al., 2020b; Lee and Min, 2015). Another crucial factor is the long-term wealth generated from natural resources, which discourages investment and savings, thereby impeding sustainable economic development (Papyrakis and Gerlagh, 2007; Ren et al., 2023c; Wang et al., 2022c).

In conclusion, this study argues that sustainable economic development in resource-based cities faces significant barriers due to limited innovative capacity, rising unemployment, and a decline in investment and savings. On the other hand, green development offers a viable and sustainable path toward harmonizing economic and environmental development by enhancing resource use efficiency, promoting green technological innovation, and creating employment opportunities (Kasztelan, 2017; Ma, 2023). Furthermore, since economic resilience is a crucial indicator of urban sustainability, we propose hypothesis 1.

H1: Green development positively impacts the economic resilience of resource-based cities.

2.2 Theoretical mechanism through which green development affects economic resilience

As China faces increasingly severe environmental challenges, the government's recognition of the significance of environmentally sustainable development is growing, leading to the implementation of numerous green policies. As a result, a considerable amount of existing research has explored the impact and relevance of green development policies on economic development from a policy perspective (Yao et al., 2023). These findings consistently demonstrate that green development policies contribute to the sustainable development of the economy and environmental protection (Winfield and Dolter, 2014; Duan et al., 2023).

Previous studies have established that effective green policies can stimulate economic growth and foster green development by enhancing productivity and competitiveness (Rubashkina et al., 2015; Ge et al., 2023). This indicates that green policies create a mutually beneficial scenario for economic development and environmental improvement (Lin and Zhu, 2020). Furthermore, green policies can have a positive influence on technological innovation. On the one hand, firms tend to counterbalance the costs associated with environmental compliance through technological innovation, thereby promoting sustainable development (Wu et al., 2022; Wang, 2023b). On the other hand, the implementation of green policies propels technological advancements in traditional industries and improves waste management practices, thereby facilitating the convergence of green development and economic growth (Zhu and Lee, 2022).

Considering the administrative structure in China, there is a nested relationship between provincial and prefecture-level municipalities. This study argues that the degree of provincial support for the implementation of green policies has a significant impact on the harmonious coexistence of economic and green development in resource-based cities. Based on the aforementioned analysis, we propose the following hypotheses.

H2: Provincial green policy support significantly enhances the positive relationship between green development and economic resilience.

3 Methodology and data

3.1 Study area and data

This study concentrates on resource-based cities in China for several reasons. First, China possesses abundant natural resources and is home to a substantial number of resource-based cities on a global scale. These cities play a pivotal role in propelling China's industrial system and fostering economic growth.

Second, resource-based cities face challenges resulting from their heavy reliance on natural resources and outdated production methods, compounded by economic system reforms (Yan et al., 2019). These challenges include a consistent industrial structure, limited technological innovation, heightened pollutant emissions, and resource constraints. The imperative of aligning environmental sustainability with economic development has become increasingly prominent in these cities, with transition cases such as Jiawang District in Xuzhou city highlighting the importance of green development.

According to the "Plan of Sustainable Development for Resource-based Cities in China (2013–2020)" issued by the State Council (2013), China is home to a total of 262 cities classified as resource-based. For the purposes of this study, our focus will be on prefecture-level cities. Due to limitations in data availability, we select a sample of 113 resource-based cities from the original pool of 126 prefecture-level administrative regions. The research timeframe for this study spans from 2011 to 2019. Data from *China Urban Statistical Yearbook*, *China Energy Statistical Yearbook*, and *National Economic and Social Development Statistical Bulletin* of each province and city are utilized. In instances where city-specific data are unavailable, we employaverage interpolation and a recursive method of calculating average annual growth rates over the preceding five years.

3.2 ER measurement methodology

Martin and Gardiner (2019) proposed a dynamic framework for analyzing and quantifying economic resilience. They argued that regional economic resilience is a multistage developmental process consisting of four interconnected phases: vulnerability, resilience, redirection, and recoverability. Specifically, regions with greater vulnerability tend to exhibit lower resistance, indicating greater susceptibility to economic shocks and disruptions. Redirection and resilience are also intertwined, suggesting a region's ability to adapt and transform its economy to enhance resilience in the face of challenges and expedite recovery to its previous level of economic performance. An accurate assessment of economic resilience necessitates an understanding of the dynamic nature of the economic cycle. Before evaluating resistance or resilience, it is essential to determine the stage of the current economic cycle. This enables an effective analysis of the region's capacity to withstand external shocks and overcome economic crises.

In this study, we categorize economic cycles primarily based on gross domestic product (GDP) growth rates. Figure 1 illustrates the overall GDP growth rate in China, which indicates a declining trend from 2011 to 2019. Given that the rate of change in GDP in resource-based cities can be considered somewhat aligned with the general economic trend in China, the selected period for this study can be defined as a recessionary period.

After identifying the economic cycle, this study utilizes the growth rate of GDP as a measure of regional resilience during a recession. The measurement methodology employed is based on the core variable approach (Martin et al., 2016), allowing for a qualitative analysis of the recession experienced during the specified period. The approach utilized in this study compares the actual change in GDP within a resource city during a recessionary period with the expected change in economic output, typically represented by the national trend. This comparison is quantified using the following formula:

$$(\Delta E_r^{t+k})^{\text{expected}} = \sum_i E_r^t * g_N^{t+k}. \quad (1)$$

In this equation, $(\Delta E_r^{t+k})^{\text{expected}}$ indicates the expected change in GDP of resource-based city r from period t to period $t + k$, g_N^{t+k} indicates the rate of change in national

Fig. 1 Economic cycle segmentation.

GDP during the recession, and E_r^t indicates the initial GDP of a resource-based city r. Therefore, the ER can be expressed by Eq. (2):

$$Resis_r = \frac{\Delta E_r^{t+k} - (\Delta E_r^{t+k})^{\text{expected}}}{|(\Delta E_r^t)^{\text{expected}}|}. \quad (2)$$

$Resis_r$ denotes the resilience of resource-based city r during economic downturns, i.e., ER, ΔE_r^{t+k} denotes the actual change in GDP of resource-based city r from period t to period $t + k$, and $(\Delta E_r^{t+k})^{\text{expected}}$ indicates the expected change in GDP of resource-based city r over period t to $t + k$. When $Resis_r < 0$, resource-based cities have lower ER than do the nation as a whole. When $Resis_r > 0$, resource-based cities exhibit higher levels of ER than the country as a whole. To discount the effect of price factors, we use the GDP price index to deflate economic output for the period 2011–2019, using 2010 as the base period, and measure ER through deflated GDP.

3.3 Green development measurement methodology

The explanatory variable in this paper is green development. Considering that GTFP includes energy, the environment, and the economy (Qin et al., 2023; Lee et al., 2023a), GTFP is selected as the measure of the green development level.

The Malmquist–Luenberger productivity index (Chung et al., 1997), also known as the ML productivity index, offers two primary advantages. First, this method avoids assumptions regarding prices and production behavior, reducing the potential influence of subjective judgments on the outcomes. Second, it resolves the issue of inconsistency between input and output units during data processing, minimizing bias arising from measurement unit changes.

This study incorporates desired and undesired outputs based on the method proposed by Chung et al. (1997) and drawing on Tone and Tsutsui (2010). This measurement method employs a nonradial, nonrectangular directional distance function using the slack-based measurement (SBM) method combined with the global Malmquist–Luenberger (GML) index to assess GTFP. The formula for calculating GTFP is defined as follows:

$$GML^{t,t+1} = (a^t, b^t, a^{t+1}, b^{t+1}, x^{t+1}) = \frac{1 + D^G(a^t, b^t, x^t)}{1 + D^G(a^{t+1}, b^{t+1}, x^{t+1})}. \quad (3)$$

In the given equation, a represents the input, b represents the desired output, and x represents the undesired output. The symbol denotes a directional distance function. The GML productivity index represents the growth rate of GTFP from period t–1 to period t. This index incorporates changes in both desired and undesired outputs, providing a comprehensive measure of productivity growth in terms of green development. As a result, the GTFP value for the base period is standardized to 1. This value is then multiplied by the annual GTFP growth rate (GML) index to calculate the GTFP for each subsequent year. The specific input and output indicators are presented in Table 1.

The energy input component for each resource-based city in this study includes the annual consumption of coal, natural gas, liquefied petroleum gas, and electricity. The labor input in resource-based cities is assessed using the annual employment per unit and conversion factors that standardize each type of energy to the equivalent amount of coal. The "perpetual inventory method" estimates capital input using the following formula:

$$K_{it} = I_{it} + (1 - \sigma_{it}) K_{it-1}, \tag{4}$$

$$K_i = \frac{I_i}{g + \sigma}, \tag{5}$$

where K_{it} denotes the capital stock of city i in year t (million dollar), I_{it} denotes the amount of fixed-asset investment in city i in year t (million yuan), and σ_{it} is the depreciation rate. We utilize a depreciation rate of 9.6% based on the study by Zhang et al. (2004). The formula for calculating the capital stock in the base period is provided by Eq. (5). The average annual growth rate (g) of fixed asset investment from 2011 to 2019 is used, with the investment amount deflated using 2010 as the base period.

In the measurement system, the outputs consist of both desired and undesired components. The desired outputs are determined by the GDP, which is adjusted to reflect the value in 2009. On the other hand, the undesirable outputs are represented by the emissions of major pollutants, namely, wastewater, sulfur dioxide, and soot and dust.

3.4 Model setting

3.4.1 Spatial econometric models

The first law of geography (Tobler, 1970) emphasizes that regions are not isolated entities and that proximity plays a crucial role in determining the level of interconnectedness among various factors. Failure to consider spatial correlation can lead to biased estimates. Therefore, this study utilizes a spatial econometric model to investigate the relationship between GTFP and ER in resource-based cities. Commonly used spatial econometric models include the spatial error model (SEM), the spatial lag model (SAR), and the spatial Durbin model (SDM), as highlighted by Elhorst et al. (2012).

$$ER_{it} = \alpha + \rho \sum_j w_{ij} ER_{jt} + \beta GTFP_{it} + \gamma X_{it} + \mu_i + \varepsilon_{it}, \tag{6}$$

$$ER_{it} = \alpha + \beta GTFP_{it} + \gamma X_{it} + \mu_i + \varepsilon_{it}, \varepsilon_{it} = \lambda \sum_j w_{ij} \varepsilon_{jt} + \epsilon_{it}, \tag{7}$$

$$\begin{aligned} ER_{it} = \alpha + \rho \sum_j w_{ij} ER_{jt} + \beta GTFP_{it} + \theta \sum_j w_{ij} GTFP_{jt} \\ + \gamma X_{it} + \varphi \sum_j w_{ij} X_{jt} + \mu_i + \varepsilon_{it}. \end{aligned} \tag{8}$$

The SAR, SEM, and SDM are shown in Eqs. (6), (7), and (8), respectively. In these equations, the subscripts i, j, and t represent resource city i, resource city j, and time t, respectively; ER indicates economic resilience; and GTFP denotes total green productivity. X_{it} is the control variable, μ indicates the regional fixed effects, and ε_{it} represents the random error term. The matrix element of the spatial weight matrix is denoted by w_{ij}. For this study, the spatial weight matrix employed is based on the geographic distance matrix.

3.4.2 Spatial weight matrix

This study utilizes the inverse distance geographic matrix to capture spatial relationships based on the desired geographic proximity. Its mathematical expression is provided below:

$$W = \begin{pmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & & \vdots \\ w_{n1} & \cdots & w_{nn} \end{pmatrix}, \tag{9}$$

$$W_{ij} = \frac{1}{d_{ij}}. \tag{10}$$

Table 1 System of indicators for measuring GTFP

Target level	Guideline level	Indicator level	Unit
Inputs	Energy	Annual coal consumption	Million tonnes of standard coal
	Labor	Number of employees	Per unit million people
	Capital	Fixed asset investment in the whole society	Million yuan
Desired output	Economic	Regional GDP	Million yuan
		Industrial wastewater emissions	Million tonnes
Non-desired output	Environment	Industrial SO_2 emissions	Tonnes
		Industrial fume and dust emissions	Tonnes

According to the first law of geography, the weight of influence decreases as the distance between two locations increases, while it increases as the distance decreases. Therefore, the IDWM is a suitable model that aligns with the understanding of spatial relationships. It quantifies the relationship between more distant spaces by taking the inverse of the geographical distance between two regions. Mathematically, Eq. (10) presents the expression for the inverse distance weight matrix, where W_{ij} represents the weight or influence between resource-based cities i and j, and d_{ij} represents the geographical distance between two cities.

3.5 Variable descriptions

Dependent variable: Urban economic resilience, as defined by Martin (2012), pertains to a city's ability to maintain stability in its economic system or transition toward emerging stable development trends. This concept effectively serves as an indicator of a city's economic sustainability (Deng et al., 2023; Faggian et al., 2018). Hence, this study designates economic resilience as the dependent variable. The dependent variable in this study is the ER of each resource-based city. Section 3.2 outlines the specific steps and measures for assessing the level of resistance.

Independent variable: GTFP, as outlined by Tian and Pang (2022), includes considerations of energy consumption, environmental pollution, and economic efficiency, rendering it a robust indicator of regional green development. Therefore, this study employs GTFP as the independent variable of interest. Green development is assessed using the GTFP metric, and the slack-based measure (SBM) approach is employed as the measurement technique. Section 3.3 outlines the specific steps and procedures for measuring green development.

Control variables: Following previous studies (Tan et al., 2020), the control variables considered in this study include the fiscal balance ratio (FRE), GDP growth rate (GGR), unemployment rate (UR), and investment support level (IC). The variable definitions are listed in Table 2.

4 Empirical results

4.1 Descriptive statistics

Table 3 displays a statistical summary of the main variables. The ER exhibits a mean value of −1.0756, displaying a significant disparity between the maximum and minimum values (a difference of 14.8243) and a standard deviation of 1.0835. These statistics indicate a generally low level of ER in resource-based cities, marked by significant variations among different cities. Resource-based cities have an average GTFP of 0.8271, with a standard deviation of 0.3293. These findings imply that the implementation of green initiatives in these cities is relatively at an early stage of development.

4.2 Spatial metrological tests

To assess spatial autocorrelation among the variables, both global and local tests are conducted. The global Moran index is used as an analytical tool to evaluate overall spatial autocorrelation in ER across resource-based cities. This index measures spatial dependence, allowing us to examine the interrelationships among the data variables. A positive and significant Moran index indicates spatial clustering, while a significantly negative Moran index indicates spatial dispersion. The global Moran index is calculated using the following formula:

$$I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{s^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}}, \tag{11}$$

where $n = 113$, $\overline{x}$ represents the average value of the variable data, s^2 denotes the variance, x_i denotes the level of ER of resource-based city i, and W_{ij} is the spatial weight matrix. When $-1 \leqslant I \leqslant 0$, there is a negative spatial correlation in the level of ER among resource-based cities. When $0 \leqslant I \leqslant 1$, there is a positive spatial correlation of ER among resource-based cities. Table 4 displays the global Moran index for the ER levels of cities in the

Table 2 Variable definitions

Type	Variables	Definition	Measure method
Independent variable	ER	Economic resilience	$Resis_r = \frac{(\Delta E_r^{t+k}) - (\Delta E_r^{t+k})^{\text{expected}}}{\lvert(\Delta E_r^t)^{\text{expected}}\rvert}$
Dependent variable	GTFP	Green total factor productivity	The base period is set to 1 and multiplied with the annual GTFP growth rate (GML) index
Control variables	FRE	Fiscal revenue to expenditure ratio	The fiscal revenue to expenditure ratio = the local fiscal expenditure/local fiscal revenue
	GGR	GDP growth rate	Annual GDP growth rate = (GDP at constant prices for the year/GDP at constant prices for the same period of the previous year) × 100
	UR	Unemployment rate	Unemployment rate = Unemployed population/(Unemployed population + Employed population) × 100
	IC	Investment capacity	Investment capacity = the amount of fixed asset investment/regional GDP

Table 3 Variable definitions

Variable	Number	Mean	Maximum	Minimum	Std. Dev.
ER	1017	−1.0756	6.7341	−8.0902	1.0835
GTFP	1017	0.8271	2.8173	0.2407	0.3293
FRE	1017	0.4039	1.1156	0.0848	0.0494
GGR	1017	0.0810	0.2396	−0.1938	0.0429
UR	1017	0.0091	0.1041	0.0012	0.0104
IC	1017	0.6759	7.8889	0.1113	0.5628

Notes: Std. Dev. represents the standard deviation.

Table 4 Global Moran's index of economic resilience

Year	*I*	*Z*	*p*
2011	0.031	2.850	0.004
2012	0.016	1.737	0.082
2013	0.050	5.667	0.000
2014	0.241	17.456	0.000
2015	0.062	5.149	0.000
2016	0.199	15.298	0.000
2017	0.049	4.038	0.000
2018	0.029	2.688	0.007
2019	0.088	6.844	0.000

respective years.

Table 4 shows that from 2011 to 2019, the ER indices of resource-based cities exhibit a significant positive trend, and the associated Z values for the ER indices all yielded significant results, indicating a positive spatial spillover effect among diverse resource-based cities. Additionally, this result suggests a spatial clustering characteristic of ER in these cities.

Although the global Moran index provides a comprehensive view of the spatial correlation in ER among resource-based cities, it may not visually represent the spatial correlation among individual cities. To address this issue, we develop local Moran scatter plots, which offer a more visual depiction of local spatial correlations. Figures 2 and 3 display the local Moran scatter plots for the 2011 and 2019 ERs, respectively. These scatterplots provide clearer insights into the spatial correlation between different resource-based cities.

In the local Moran scatterplot, the horizontal axis represents the normalized ER value, while the vertical axis represents the spatial lag value. The discrete points on the scatterplot are distributed across different quadrants, and their quadrant distribution characteristics illustrate the spatial characteristics of urban ER. As shown in the figure, there are more scattered points distributed in the first and third quadrants, indicating a positive spatial correlation of ER among the majority of resource-based cities. Specifically, the economic resilience of resource-based cities is characterized by spatial clustering.

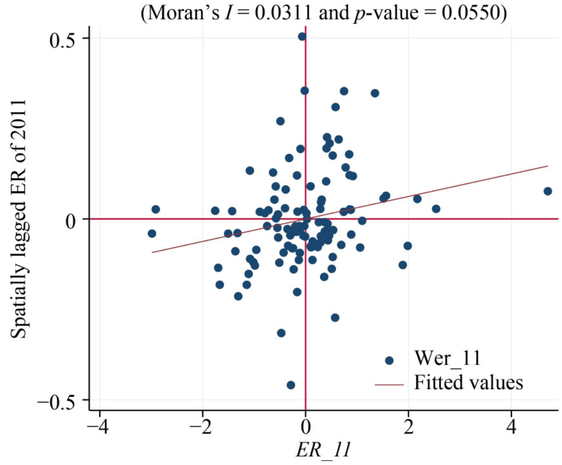

Fig. 2 2011 Moran' *I* scatter plot of ER.

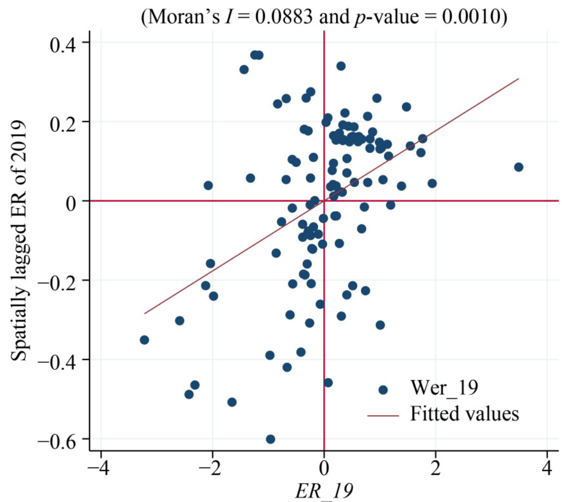

Fig. 3 2019 Moran' *I* scatter plot of ER.

In summary, the global Moran index and the Moran scatterplot indicate a positive spatial effect on the economic resilience of resource-based cities. This highlights the importance of considering spatial factors when exploring the impact of green development on economic resilience.

4.3 Benchmark regression results

We follow the approach of Liu et al. (2017), who use the Hausman test, Lagrange multiplier (LM) test, and robust LM test to select appropriate spatial regression models for conducting spatial econometric regression. By employing these tests, the validity and reliability of the spatial regression models selected in this study were enhanced.

Based on the test results, we find that the null hypothesis of no spatial correlation in the model residuals is rejected (p-value = 0.000) according to the LM-error and Robust LM-error statistics. However, the p-value of the robust

LM-lag test is insufficient to reject the null hypothesis of no spatial lag. Therefore, it can be concluded that a spatial error model should be employed in this study. Additionally, the Hausman test yields a p-value of 0.000, indicating that the null hypothesis of exogeneity (random effects) is rejected. Thus, a fixed-effects model is deemed more appropriate for this study. Consequently, based on the results of these tests, we recommend using the spatial error model in combination with a fixed-effects model for regression analysis. Specific results are shown in Table 5.

The influence of GTFP on ER in 113 resource-based cities is empirically tested using a spatial error model. The estimated results are obtained through a benchmark regression using maximum likelihood estimation (MLE). To validate the spatial model and ensure robust findings, regression results from the SDM and SAR models are included for comparison in Table 6.

Table 6 shows that the coefficients of GTFP in all three models display significant positive values. This indicates a positive association between ER and GTFP, suggesting that a higher level of green development contributes to improved economic resilience. The results from the SEM further affirm this relationship, as they show that 1 unit increase in GTFP is estimated to lead to 0.5112 units increase in ER. These findings confirm green growth theory (OECD, 2011), which directly addresses the connection between green development and economic sustainability.

Table 5 LM (Robust) test

Test	Statistics
LM-error	321.311(0.000)
LM-lag	91.451(0.000)
Robust LM-error	229.887(0.000)
Robust LM-lag	0.027(0.868)
Hausman test	33.98(0.000)

Notes: p-values are in parentheses.

Table 6 Benchmark regression results

	SDM	SAR	SEM
GTFP	0.5387***	0.5294***	0.5112***
FRE	0.4194	0.3393	0.4015
GGR	6.7602***	6.4318***	6.9236***
UR	−1.5076	−1.2035	−2.2628
IC	−0.0724	−0.0730	−0.0579
WGTFP	2.5642*		
λ	0.7686***	0.7750***	
α			0.7739***
regional effect	control	control	control
time effect	control	control	control
number of idcode	113	113	113
N	1017	1017	1017

Notes: standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In contrast to Tian and Feng (2023) and Chen et al. (2023), our study produces positive results that align with their findings while also revealing some distinctions. Previous research has predominantly examined how the level of regional green development indirectly influences local economic sustainability through factors such as green technological innovation, green financial development, and environmental regulation (Li et al., 2023a; Tariq and Hassan, 2023 Hung, 2023). However, our study takes a different approach by utilizing GTFP to create green development indicators that integrate economic output, environmental performance, and energy consumption. This allows us to directly investigate the positive relationship between regional green development and economic resilience. Furthermore, our study highlights that the rational utilization of natural resources, more efficient energy usage, and increased environmental protection are crucial strategies for achieving sustainable economic growth.

4.4 Robustness tests

To ensure the reliability of our conclusions, we conduct robustness tests. In the first test, we employ an SEM constructed using spatial nested moments and an economic distance matrix array as an alternative to the inverse distance matrix used in the initial analysis.

The nested matrix, which incorporates both geographic distance and per capita GDP as elements, can be mathematically expressed as follows:

$$C_{ij} = (1/|PGDP_j - PGDP_i + 1|) \times e^{-d_{ij}}, \qquad (12)$$

where C_{ij} is the nested matrix. $PGDP_i$ and $PGDP_j$ denote the per capita GDP of cities i and j, respectively, and d_{ij} denotes geographical distance.

We then proceed to conduct further robustness tests by shortening the time window, which allow us to exclude the effects of other policies on the results. During the benchmark analysis of this study, the time window considered spans from 2011 to 2019. However, in 2013, the central government of China implement significant initiatives to facilitate the development of resource-based cities. These initiatives include allocating substantial funds amounting to 16.8 billion yuan for supporting resource-depleted cities through urban transfer payments. Additionally, subsequent to 2013, the central government of China introduce a variety of industrial support policies specifically targeting resource-based cities. As part of our robustness check, we shorten the time window to 2013–2019. The detailed findings from this analysis are presented in Table 7.

The table reveals that the spatial error coefficient (α)

Table 7 Robustness test

	SEM (substitution matrix)	SEM (shortened time)
GTFP	0.6938***	0.5444***
FRE	0.3891	0.4518
GGR	6.7370***	7.3313***
UR	−2.4378	−1.3738
IC	−0.0629	−0.2474**
α	0.6466***	0.7715***
regional effect	control	control
time effect	control	control
number of idcode	113	113
N	1017	791

Notes: standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 8 Heterogeneity analysis

	Growth	Maturity	Regeneration	Decline
GTFP	1.2627**	0.7969***	0.5842**	0.1053
FRE	0.4641	0.1519	−0.6496	1.7407**
GGR	9.9356**	7.1298***	7.5190***	5.4926***
UR	−20.6159	1.9211	7.3444	−6.0033
IC	0.3135	−0.0355	−0.9057	−0.7385
α	−0.4596**	0.6197***	0.2064	−0.3436*
regional effect	control	control	control	control
time effect	control	control	control	control
number of idcode	14	61	15	23
N	126	549	135	207

Notes: standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

remains significantly positive, indicating the persistence of spatial dependence in the model. Additionally, the coefficient for GTFP is estimated at 0.5444, demonstrating statistical significance at the 1% level. This observation suggests that GTFP continues to exert a significant and positive influence on ER, even when the study's temporal scope is limited.

4.5 Heterogeneity analysis

Our study provides empirical evidence supporting the idea that green development can bolster economic resilience in resource-based cities. To explore potential variations in the influence of green development on economic resilience and identify differences in influencing factors among various types of resource-based cities, we conduct a comprehensive analysis of heterogeneity within our study cohort. The classification of resource cities in our study aligns primarily with the guidelines outlined in the National Sustainable Development Plan for Resource Cities (2013–2020) by the State Council (2013). This plan categorizes resource-based cities into four groups: growth, maturity, regeneration, and decline.

In our analysis, the 113 resource-based cities are categorized into 14 growing, 61 mature, 15 regenerative, and 23 declining groups. We construct separate inverse geographic distance matrices for each type of resource city and employ a spatial error model for analysis, as outlined in Table 8.

As shown in Table 8, the spatial impact on economic resilience is notably negative for both growing and declining resource-based cities, indicating a tendency toward spatial dispersion in the economic resilience of these groups. In contrast, the positive and significant spatial error coefficient for mature resource-based cities suggests that enhancements in economic resilience within this category positively affect economic resilience in similar resource-based cities. However, the spatial effect on economic resilience for regenerative resource-based cities is found to be statistically insignificant.

Moreover, our findings suggest that the GDP growth rate significantly contributes to the economic resilience of all four types of resource-based cities. Conversely, green development significantly contributes to the economic resilience of only growing, mature, and regenerating resource-based cities without significantly impacting the economic resilience of declining resource-based cities. For declining resource-based cities, the fiscal capacity of local governments hasemerged as a key factor in enhancing economic resilience. Consequently, various types of resource cities should pursue sustainable development paths tailored to local conditions to foster economic resilience.

5 Analysis of the moderating effects

The policy environment has a significant influence on urban development, shaping its trajectory and level (Hu et al., 2023; Li et al., 2013). However, studies often overlook the nested relationship between the provincial and prefectural levels when examining the impact mechanism at the prefecture level. This oversight hampers a comprehensive understanding of the complex dynamics and interactions between different policy levels and their effects on urban development. It is therefore crucial to consider the actual nested relationship between the provincial and prefectural levels to achieve a comprehensive analysis of the influence of the policy environment on urban development outcomes.

In line with this, our study aims to explore the potential impact of provincial green policies on the relationship between green development and ER in prefecture-level cities. To investigate this, we utilize the degree of green development policy support as a means to examine the moderating mechanism. We adopt the measurement method proposed by Li and Pan (2011), which specifically focuses on assessing China's green development policy support. We construct an evaluation index system based on three dimensions: green investment, infrastructure and urban management, and environmental governance. The entropy method is used as a specific measure. Please refer to Table 9 for the detailed index system.

In our study, we propose the degree of green development policy support as a moderating variable to examine its role in the relationship between green development and ER. The results of this moderating mechanism are presented in Table 10. Our analysis demonstrates that the coefficients of the main explanatory variables remain positive and statistically significant at the 10% level, in accordance with Hypothesis 1. However, upon introducing the interaction term, we observe a significant coefficient of 6.8363 at the 5% level. This indicates that the degree of policy support for green development significantly moderates the positive relationship between green development and economic resilience in prefecture-level cities.

The similarities between our findings and those of Kuang and Lin (2022) may be attributed to the significant impact of government policies on green and environmental protection. These policies greatly stimulate regional green economic activities, including green investments, financial practices, and energy transitions (Hu et al. 2023; Yao et al. 2023; Liu et al. 2023). This reinforcement strengthens the connection between green development and economic sustainability. However, our findings differ slightly from those of previous studies that examine only the impact of policies on prefecture-level cities (Zhang et al., 2023; Chen et al., 2023). Instead, due to China's unique political governance system, our study delves into the moderating role of the provincial policy environment in which the region is embedded, revealing the nested effects between the province and prefecture-level cities. From these results, it is evident that prefecture-level cities should respond positively to provincial policy support to expedite the energy transition through green development strategies and increase green investments to enhance economic resilience (Cao and Tao, 2023; Huang, 2023). This finding provides valuable insights for promoting the effectiveness of green development policies in resource-based urban areas (Tawiah et al. 2021).

Table 9 System of indicators of Provincial Green Development

Target level	Guideline level	Indicator level
Degree of policy support	Green investment indicators	Percentage of expenditure on environmental protection, percentage of investment in environmental pollution control, etc.
	Infrastructure and urban management	Urban green space per capita, sewage treatment rate
	Environmental Governance Indicators	Industrial waste removal rate, etc.

Table 10 Moderating effects

	SEM
GTFP	0.6703***
GP	−4.2820
GTFP*GP	6.8363**
FRE	0.4243
GGR	7.0238***
UR	−2.2467
IC	−0.0517
regional effect	control
time effect	control
number of idcode	113
N	1017

Notes: standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6 Conclusions and policy implications

Our study examines the influence of green development on the ER of resource-based cities, emphasizing the role of green development in achieving the goal of sustainable economic development. We utilize a panel data set of 113 resource-based cities over the period 2011–2019. To analyze this relationship, we employ SEM. In addition, we conduct a heterogeneity analysis and explore the potential moderating role of provincial green development policies in this impact.

Our study yields several critical findings. First, we observe a significant positive relationship between GTFP and the ER of resource-based cities. This implies that higher levels of green development in these cities contribute to improved economic stability and sustainability, thereby mitigating the negative impacts associated with the resource curse. Second, we observe variations in the influencing factors among diverse types of resource-based cities, and the impact of green development varies across these types. Green development has the greatest influence on growing-resource cities, while it has no significant impact on declining-resource-based cities. Finally, we observe that the green development policies implemented by the provinces where resource-based cities are situated act as important moderating variables. Specifically, provincial green development policies can promote a positive relationship between green development and economic resilience.

Based on our research findings, we present the following insights. First, resource-based cities should prioritize the advancement of green transformation. This includes promoting green technological innovation, improving environmental governance, and prioritizing the construction of ecological environments. These measures are crucial for improving economic resilience while simultaneously pursuing the sustainable goal of green development and striving to decouple economic growth from resource consumption and environmental pollution.

Second, resource-based cities should explore suitable paths for sustainable economic development and enhance their economic resilience in accordance with local conditions.

Third, provinces should establish a supportive policy framework for green development in resource-based cities. Provincial governments play a crucial role in promoting the impact of green development on enhancing the economic resilience of prefecture-level cities. This can be achieved through policies that strengthen environmental protection, actively encourage and support green technological innovation within provinces, and provide guidance.

In summary, resource-based cities and provincial governments must collaborate to foster sustainable development, embracing green development as a means to strengthen economic resilience while preserving the environment.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

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