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# Is It Feasible for China's Resource-Based Cities to Achieve Sustainable Development? A Natural Resource Dependence Perspective

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**Abstract:** Theoretically, regions with rich natural resources often tend to develop resource-based industries more intensively, resulting in resource-dependent land development. China's resource-dependent cities exhibit certain exceptions. Natural resource dependence (NRD) plays a relatively positive role in the total factor productivity change (TFPCH) in these cities, primarily attributable to their relatively mature technological efficiency. However, while such positive impacts exist, their overall effect remains limited. Many resource-based cities in China still face challenges in achieving sustainable growth. This raises a key question: why have some resource-based cities failed to achieve sustainable development? In order to explore the root cause of this problem, this paper systematically analyses the impact of resource dependence on TFPCH, and its governance mechanism based on the balanced panel data of 112 resource cities in China from 2003 to 2021, using the Super-SBM-DEA-Malmquist index method in the first stage, and the OLS model in the second stage. The main findings of this paper are as follows: First, NRD has a significantly positive impact on TFPCH, especially in growing and regenerating cities. The empirical results further validate the applicability of the resource blessing theory in China. Second, government regulation has a dampening effect on TFPCH in resource cities, which suggests that in the future development of resource cities, government intervention should be moderately reduced, and more emphasis should be placed on stimulating the city's own autonomous mobility and endogenous development drive. Third, heterogeneity analyses show that this promotional effect is mainly realized through the improvement of technical efficiency. Fourth, the analysis of the moderation effect shows that research and development (R&D) intensity plays a positively moderating role in the sustainable development of resource-based cities. Through a stepwise approach, this paper reveals why resource-based cities cannot achieve sustainable development. The level of R&D in some resource-based cities remains relatively low, while it is the key factor for the applicability of the resource blessing (RB) hypothesis in China's resource city. The findings not only provide new perspectives for theoretical research, but also important policy recommendations for the sustainable governance of land use in resource-based cities worldwide.

**Keywords:** nature resource dependence; research and development; total factor productivity change index; Super-SBM-DEA-Malmquist; land use

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## 1. Introduction

In the early stages of China's economic development, resource-based cities leveraged their abundant natural resources to drive rapid social and economic progress, making significant contributions to the country's overall economic growth [1]. Studies have shown that regions with rich natural resources generally experience higher economic growth rates than resource-scarce regions, as natural resources drive social and economic development [2,3]. A prominent example could be found in Heilongjiang Province, one of China's key energy-producing regions based on its affluent resources. In 2011, the province's gross domestic product (GDP) reached CNY 993.5 billion, with an impressive growth rate of 10.9% [4]. This emphasizes the critical role of natural resources in driving regional economic development. As Heckscher–Ohlin's theorem says, the early capital accumulation of the United States helped it to be a leader in market-oriented capitalism worldwide [5]. However, despite its initial performance of robust economic growth, Heilongjiang's GDP growth rate has exhibited a persistent downward trend over the past decade. By 2024, the growth rate dropped to 3.2%, a much lower level in China, reflecting the fact that resource-intensive economic development is facing serious challenges. Thus, how to maintain economic growth has become an urgent issue that needs to be addressed. This phenomenon once again brings to the forefront the ongoing debate over whether natural resources serve as a blessing or a curse for regional development, a question that remains unresolved.

The paradoxical theories of the resource blessing (RB) and resource curse (RC) originate from the phenomena of Dutch Disease, which describes the decline of domestic manufacturing as a consequence of resource trade activities. This phenomenon has drawn significant scholarly attention [6]. Sachs and Warner (1995) for the first time confirmed the existence of the RC in their empirical analysis [7], which further led to extensive research on the RC hypothesis [8,9]. However, while the RC hypothesis provides insights into certain economic challenges, its application and validity remain subjects of debate. The RB hypothesis emerged as a counterargument, suggesting that resource abundance can, under the right conditions, contribute positively to economic growth and development [10]. They found that natural resources play a significant role in promoting financial development. Similarly, the authors of refs. [11,12], through case studies on Norway and Indonesia, respectively, have demonstrated that the resource curse is not a universal phenomenon, highlighting that resource abundance can, under certain conditions, contribute positively to economic growth and financial stability. Regrettably, the early literature primarily focused on the relationship between natural resources and economic growth [13,14], overlooking the broader implications for economic efficiency.

Moreover, the Chinese government has set ambitious targets for sustainable low-carbon development, aiming to deepen the transition by 2027 and achieve a steady decline in carbon emissions after 2035. Against this policy backdrop, unfortunately, the traditional model of resource-based cities relying solely on resource extraction at the expense of the environment is no longer sustainable. Given the high energy consumption and its resulting pollution, transforming the economic growth model toward a carbon-zero economy has become an urgent priority. In this context, improving total factor productivity (TFP) is increasingly recognized as a key driver of sustainable development. Consequently, the relationship between natural resource extraction and its environmental-friendly economic efficiency has drawn increasing attention from scholars [15,16]. However, the existing studies largely use natural resource abundance (NRA) as a measure of natural resource endowment, while the research focusing on natural resource dependence (NRD) remains limited. Resource-based cities in China are often trapped in their traditional development paradigm, where reliance on resource industries is not one of the options, but just the survival kit. Therefore, using NRD as a measurement indicator provides a more accurate

reflection of the economic realities faced by China's resource-based cities. Shao adopted a measurement index more suitable for China's national context, using NRD to assess variations in natural resource endowments among resource-based cities. He found a significant inverted U-shaped relationship between NRD and total factor productivity, suggesting that while NRD may initially contribute to economic growth, its positive effects might not be sustainable as the local economies grow [15]. However, due to the subjective selection of city samples in his study, the reliability of this RB test remains open to debate. In order to improve the accuracy of the findings, therefore, 112 resource-based cities in China are selected as samples in this paper, aiming to reduce the problems caused by subjective city selection. Additionally, our research explores the mechanisms through which resource-based cities can achieve sustainable and effective development by incorporating a moderating effect. By optimizing the research design and controlling for potential biases, our research will make efforts for more precise and robust empirical results.

In its national governance context, China is unique in that the government has supreme power for selective concentration, and thus is able to achieve multiple goals more systematically. In this perspective, can resource dependence have a positive and sustainable performance on China's resource-based cities? Can the RB hypothesis be applied in China? In order to answer these questions, this research shall take a stepwise approach to the governance factors. We firstly evaluate the total factor productivity change (TFPCH) of 112 resource-based cities (Table A1) by the Super-SBM-DEA-Malmquist index method, then we verify the RB hypothesis in China by the impact of NRD on TFPCH of resource-based cities in China using OLS regression. For the governance of this mechanism, we further introduce research and development (R&D) as a moderating variable to explore the key factors of NRD affecting the sustainable development of resource-based cities. Additionally, this paper will offer significant insights for resource-based cities to be developed in more sustainable ways in the future. For this evaluation, our research will explore the trade-offs between the development of different resource types to promote sustainable land development.

The rest of the study is structured as follows: the literature review and hypotheses are presented in Section 2; the research methodology, selecting samples, and variable measurement are presented in Section 3; Section 4 provides an analysis of the empirical results, an analysis of heterogeneity, and an analysis of the mechanisms of influence; and the findings and policy implications are presented in Section 5.

## 2. Literature Review and Hypotheses

### *2.1. RB Hypothesis and Nature Resource*

The RB hypothesis has attracted extensive academic discussion since its formulation. RB means that abundant natural resources are an affordable asset to promote economic development effectively. Historically, natural resources have been crucial in shaping the future of the national economy [17]. The success of China in the early days of reform and opening up as well as the industrial revolution in the UK are all closely related to abundant natural resources, all of which prove the great value that natural resources play a key role [15,18]. Nonetheless, many other scholars emphasized natural resource volatility as a fragile driver of Asian economic growth [19,20]. They scrutinize the resource curse hypothesis for land development. They argued that an increase in natural resources positively affects the gross domestic product (GDP) of Asian economies except India, where the relationship with GDP is negative. Using data from 53 countries from 1980 to 2006, Raissi et al. (2011) concluded that oil abundance has a positive impact on real income and short-term economic growth [21]. Natural resources are seen as a core driver of sustainable economic development, contributing not only to stable economic growth, but also to

technological progress. Dwumfour et al. (2018) state that natural resource abundance contributes to the development of the financial sector [22]. More natural resource revenues will provide more liquidity to the banking sector through increased deposit flows from the private and public sectors as well as tax revenues from the government. Javadi et al. (2017) analyzed the relationship between financial development and oil rents in 70 countries between 2006 and 2014, and found a positive and significant relationship between oil rent and the financial environment in developed countries [23]. Vaona examined the consumption of non-renewable energy sources and suggested that increased consumption of non-renewable energy sources helps to drive economic growth [24]. However, as output rises, the growth rate of non-renewable energy consumption tends to decline, which may be attributable to the increase in energy use efficiency, implying the important manifestation of technological progress.

The sustainable utilization of natural resources is a critical issue that requires urgent attention in the development of resource-based cities. Analyzing natural resource-rich cities reveals that they often face significant paradoxical trade-offs related to resource development, environmental protection, and sustainability. Studies by Lorente et al. (2018) find that resource abundance contributes to lower carbon footprints, thereby improving environmental quality [25]. Ding et al. (2023) demonstrated that an abundance of natural resources can contribute to reducing carbon dioxide emissions by decreasing dependence on fossil fuel imports [26]. Similarly, Silva et al. (2012) examined the causal relationship between economic growth, $CO_2$ emissions, and renewable energy output in four countries—Denmark, Portugal, Spain, and the United States—over the period from 1960 to 2004 [27]. Their findings indicate that an increased share of renewable resources in the energy mix has a significant positive impact on reducing $CO_2$ emissions. These studies suggest that natural resource endowments can contribute to environmental benefits under certain conditions. However, Jianing Pang et al. (2024) highlight that if resource development is not guided by sustainable strategies, it may result in severe ecological degradation, resulting in irreversible environmental damage [28]. In this perspective, enhancing research and development (R&D) efforts is essential to addressing these sustainability challenges. R&D may play a crucial role in promoting sustainable natural resource development. Mondejar et al. (2021) argue that technological advancements driven by R&D have significant potential to contribute to sustainable development by creating opportunities for both environmental protection and economic growth [29]. In summary, the above literature confirms the reliability of the resource blessing effect under certain conditions, giving rise to the governance issue. Therefore, based on the comparison of the literature, this study will further explore R&D as a key influencing mechanism, examining its role in balancing resource development with sustainability objectives.

### *2.2. TFPCH in Resource-Based Cities*

In the early stages of development, many resource-based cities relied on the extraction and consumption of resources to promote economic growth. However, as the need for sustainable development increases, this resource-based quantitative growth can no longer meet long-term competitiveness. TFP of relatively abundant resources not only reflects the efficiency and effectiveness of a city's economic growth, but also reveals the sustainability of resource utilization over time. Therefore, assessing the TFP of resource-based cities is crucial for an in-depth understanding of the quality and sustainability of their economic development. Thus, resource-based cities face an urgent need to shift their development models toward qualitative or sustainable economic growth to ensure the achievement of long-term competitiveness of land development. While natural resources play a crucial role in driving economic growth, their extraction can also lead to significant environmental

challenges [30]. As concerns about resource scarcity and environmental pollution have increased, researchers have shifted their focus to analyzing the impact of natural resources on dynamic TFP [31]. This field of research attempts to figure out how the abundance and use of natural resources affect economic efficiency over time [32]. Lu et al. (2024) argue that an adequate supply of resources can have a significant positive impact on Green Total Factor Productivity (GTFP) during economic expansion due to increased investment [33]. Using the data from 2006 to 2022, Sun et al. (2024) found that natural resources have full potential for sustainable development only with strong environmental policy support [34].

Based on all these discussions above, it is evident that natural resource abundance positively contributes to high-quality economic development. Given that resource dependence serves as a key indicator of natural resource endowment, this study proposes the following hypothesis:

**Hypothesis 1:** *NRD has a positive impact on the TFPCH of resource-based cities*.

### *2.3. R&D Intensity of the Resource-Based Cities*

Natural resources, as the essential inputs in production, directly impact total regional output. However, their influence may extend beyond the direct effects; natural resources also contribute to economic growth potential through intrinsic mechanisms such as R&D. Thus, the full utilization of natural resources may further lead to high-quality economic development, but only under specific conditions such as R&D, resulting in RB. Societal support for R&D activities plays a key role in driving economic development [35]. The adequacy of R&D investment not only directly affects a regional innovation capacity, but further determines its long-term economic growth potential [36]. This section focuses on the two core concepts of natural resources and R&D to explore whether R&D serves as an effective transmission factor for the sustainable development of resource-abundant cities. According to [37], by using data from 30 regions in China from 2009 to 2021, natural resource dependence positively moderates the impact of government R&D subsidies, which means that regions with a higher degree of NRD have stronger government R&D subsidies to promote social R&D investment. That is, in cities or regions with higher resource dependence, R&D subsidies on the resource utilization provided by the government can more effectively promote matching R&D activities by the enterprises, resulting in better performance. A number of scholars have shown that R&D can help resource-based countries or cities to increase the level of innovation. Research from the Chinese manufacturing sector suggests that the impact of government R&D support systems is particularly outstanding in regions where local governments are more efficient, but less intrusive in business activities [38]. Badeeb et al. (2023) use data from the BRICS countries to examine the capability of innovation on the relationship between natural resources and economic growth and conclude that countries with higher levels of innovation can avoid the resource curse [39]. Sun et al. (2021) studied the impact of technological innovation on energy efficiency and found that technological innovation can produce spillover effects in neighboring countries [40]. Yu et al. (2022) analyzed the relationship between innovative cities and energy productivity and found that innovative cities can improve energy productivity by improving innovation quality and behavior [41].

In summary, all this research suggests that R&D serves as an effective transmission modulator that facilitates the sustainable development of resource-based cities. Based on the aforementioned literature, therefore, we will examine the following hypothesis:

**Hypothesis 2:** *R&D positively moderates the relationship between NRD and the sustainable economic development of resource-based cities*.

## 3. Data and Methodology

### *3.1. Methods*

#### 3.1.1. Super-SBM-Model

DEA is a non-parametric technique for assessing effectiveness, developed by Charnes in 1978 [42]. It utilizes a mathematical programming approach to assess the effectiveness of decision-making units (DMUs) with multiple inputs and outputs. DEA is widely applied in fields such as management and economics for efficiency measurement, as it does not require assumptions about the functional form of the relationship between inputs and outputs. This feature leads to more objective evaluation results. Furthermore, DEA has significant advantages in handling complex evaluations involving multiple inputs and outputs. However, the underlying CCR and BCC models overlook slack variables in their evaluations, potentially leading to biased results. To address this limitation, the author employs the non-radial, non-angular slack-based model (SBM), which accounts for slack variables in static efficiency analysis. Consider a set of $n$ DMUs, denoted as $DMU_j$ ($j$ = 1, 2, …, $n$), each characterized by a technical efficiency measure. Each DMU utilizes $m$ input factors and produces $q$ output factors, represented by $x_i$ (i = 1, 2…, $m$) and $y_r$ ($r$ = 1, 2, …, $q$), respectively. The formulation of the original SBM is given as follows:

$$\rho^* = \min \frac{\left(1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{ik}}\right)}{\left(1 + \frac{1}{q}\sum_{r=1}^{q} \frac{s_r^+}{y_{rk}}\right)}$$

$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} x_{ij}\lambda_j + s_i^- = x_k \\ \sum_{j=1}^{n} y_{ij}\lambda_j - s_r^+ = y_k \\ \lambda_j, s_i^-, s_r^+ \geq 0 \\ j = 1, 2, \ldots, n; \quad i = 1, 2, \ldots, m; \quad r = 1, 2, \ldots, q \end{cases} \tag{1}$$

In this model, $\rho^*$ represents the efficiency score of the DMUs, capturing inefficiencies from both input and output perspectives. This distinguishes it from the traditional DEA, which measures inefficiency from either the input or output perspective separately, making the SBM an unguided efficiency measurement approach. The variables $s_i^-$ and $s_r^+$ denote the input and output slack variables, respectively, while $\lambda_j$ represents the weight associated with the inputs and outputs of the $j$th DMU.

Unlike radial DEA models, the SBM explicitly incorporates input and output slack variables into the objective function, enabling a more comprehensive measurement of inefficiency. This formulation addresses the limitations of radial models, which fail to account for slack variables in inefficiency assessments. However, when evaluating green economic growth, it is essential to consider undesirable outputs as well. Additionally, conventional SBM may result in efficiency scores of 1 for multiple DMUs, limiting their ability to distinguish performance levels.

To overcome this limitation, the SBM super-efficiency model is introduced, incorporating undesirable outputs. The formulation under the assumption of variable returns to scale (VRS) is presented as follows:

$$\rho^* = min \frac{\left(1 + \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{ik}}\right)}{\left(1 - \frac{1}{q}\sum_{r=1}^{q} \frac{s_r^+}{y_{rk}}\right)}$$

$$s.t. \begin{cases} \sum\limits_{j=1,j\neq k}^{n} x_{ij}\lambda_j - s_i^- \leq x_{ik} \\ \sum\limits_{j=1,j\neq k}^{n} y_{ij}\lambda_j + s_r^+ \geq y_{rk} \\ \sum\limits_{j=1,j\neq k}^{n} \lambda_j = 1 \\ \lambda_j, s_i^-, s_r^+ \geq 0 \\ j = 1, 2, \ldots, n(j \neq k) \\ i = 1, 2, \ldots, m; r = 1, 2, \ldots, q \end{cases} \quad (2)$$

3.1.2. Malmquist Index Decomposition

The super-SBM is a static efficiency evaluation method. When a time factor is incorporated for dynamic data analysis, differences in production frontiers across periods can lead to estimation bias. The Malmquist index can address this issue in appropriate ways using the geometric average for the basis of time transition. Lovell refers to the frontier technology that constitutes the CRS production possibility set as the benchmark technology, which is defined as the reference technology for calculating TFP. The frontier technology that constitutes the VRS production possibility set is referred to as the best practice technology, which represents the frontier technology existing in reality. The Malmquist productivity index should be defined based on the benchmark technology, with the Malmquist productivity index for periods $t$ and $t + 1$ calculated using the respective reference technologies in Equations (3) and (4).

$$M_t\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_C^t\left(x^{t+1}, y^{t+1}\right)}{D_C^t(x^t, y^t)} \quad (3)$$

$$M_{t+1}\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_C^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_C^{t+1}(x^t, y^t)} \quad (4)$$

According to Fisher (1922), the Malmquist productivity index is symmetric in economic terms, measured by the geometric mean of these indices as the composite productivity index,

$$M\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \left(M_t^0 M_{t+1}\right)^{\frac{1}{2}} = \left[\frac{D_C^t\left(x^{t+1}, y^{t+1}\right) D_C^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_C^t(x^t, y^t) D_C^{t+1}(x^t, y^t)}\right]^{\frac{1}{2}} \quad (5)$$

There is no disagreement between FGNZ and RD regarding the Malmquist productivity index itself. The divergence lies in the decomposition of the index. The decomposition according to FGNZ is as follows:

$$M\left(x^t, y^t, x^{t+1}, y^{t+1}\right) = \frac{D_V^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_c^t(x^t, y^t)} \times \left(\frac{D_C^t(x^t, y^t) D_C^t\left(x^{t+1}, y^{t+1}\right)}{D_C^{t+1}(x^t, y^t) D_C^{t+1}(x^{t+1}, y^{t+1})}\right)^{\frac{1}{2}} \times$$
$$\frac{D_c^{t+1}\left(x^{t+1}, y^{t+1}\right) / D_V^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_C^t(x^t, y^t) / D_V^t(x^t, y^t)} = \mathrm{TE}\Delta rGNZ \times T\Delta FNZ \times S\Delta GNZ$$

The decomposition according to RD is as follows:

$$\begin{aligned} TFP &= M\left(x^{t+1}, y^{t+1}, x^t, y^t\right) \\ &= \left[\frac{D_C^t\left(x^{t+1},y^{t+1}\right)}{D_C^t\left(x^t,y^t\right)} \times \frac{D_c^t\left(x^{t+1},y^{t+1}\right)}{D_C^t\left(x^t,y^t\right)}\right]^{\frac{1}{2}} \\ &= \frac{D_v^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_v^t\left(x^t,y^t\right)} \times \left[\frac{D_v^t\left(x^{t+1},y^{t+1}\right)}{D_v^{t+1}\left(x^{t+1},y^{t+1}\right)} \times \frac{D_v^t\left(x^t,y^t\right)}{D_v^{t+1}\left(x^t,y^t\right)}\right]^{\frac{1}{2}} \times \\ &\left[\frac{D_c^t\left(x^{t+1},y^{t+1}\right)/D_v^t\left(x^{t+1},y^{t+1}\right)}{D_c^t\left(x^t,y^t\right)/D_v^t\left(x^t,y^t\right)} \times \frac{D_c^{t+1}\left(x^{t+1},y^{t+1}\right)/D_v^{t+1}\left(x^{t+1},y^{t+1}\right)}{D_c^{t+1}\left(x^t,y^t\right)/D_v^{t+1}\left(x^t,y^t\right)}\right]^{\frac{1}{2}} \\ &= TE\Delta RD \times T\Delta\mathrm{RD} \times \mathrm{S}\Delta\mathrm{RD} \end{aligned} \tag{6}$$

In this context, TEΔ, TΔ, and SΔ represent changes in technical efficiency, technological progress, and changes in returns to scale, respectively. Clearly, FGNZ and RD align in terms of the decomposition of changes in technical efficiency. However, the distinction lies in their approaches to decomposing technological progress with a return to scale. FGNZ's fundamental flaw lies in its definition of technological progress. While FGNZ acknowledges that real-world technology is in the form of VRS (variable returns to scale), and consequently calculates changes in technical efficiency and returns to scale accordingly, it neglects the real-world VRS technology when calculating technological progress. Thus, it adopts the hypothetical CRS (Constant Returns to Scale) technology. As a result, the technological progress in FGNZ's decomposition reflects progress in the reference technology, not in real-world technology. This also leads to differing definitions of changes in returns to scale between the two approaches.

### *3.2. Variable Description and Data Sources*

The description and sources of relevant variables are as follows:

(1) Input variables: (1) labor—expressed through the city's total number of employees; (2) capital—expressed as a nominal gross investment in fixed assets; and (3) energy—according to the strong correlation between energy consumption and electricity consumption, this paper adopts the indicator of citywide electricity consumption to measure energy consumption.

(2) Output variables: (1) Expected output—measured using gross regional product and excluding the effect of price factors, using 2003 as the base period. (2) Undesired outputs—industrial wastewater discharges. (3) Undesired output—industrial Sulfur dioxide emissions.

(3) Control variables: (1) per capita gross domestic product (pgdp); (2) primary sector as a percentage of GDP (Struc); (3) foreign direct investment (fdi); (4) expenditures within the local budget (gov); and (5) the total number of patents granted (patent).

In measuring dependence on natural resources, commonly used indicators include the proportion of resource-extracting industry output or employment. However, at the city level in China, only data on employment is available. Therefore, following the approach of [15], this study adopts the proportion of resource-extracting employment in total employment as a measure of resource industry dependence. According to China's current industrial classification standards, the resource-extracting sector includes coal mining, oil and gas extraction, and ferrous metal ore mining, comprehensively covering industries related to natural resources. Consequently, this indicator provides a relatively accurate measure of resource dependence from the perspective of employment. A higher share of labor absorbed by the mining sector indicates greater economic reliance on resource-based industries.

Sadao [43] states that patent information is increasingly being used to analyze innovation and its process, and thus patent statistics are increasingly being used as an important

indicator to measure innovation. Thus, the number of patents is used in this paper to measure the degree of innovation.

The data are derived from the China Statistical Yearbook, China Urban Statistical Yearbook, and provincial statistical yearbooks. Data sources include China Urban Statistical Yearbook 2004–2022 and official statistical yearbooks published by provinces and cities. The China Carbon Accounting Database and statistics yearbooks at all levels provide the energy data. Linear interpolation is used to improve and supplement the lacking data. The model's variables' descriptive statistics are listed in Table 1.

**Table 1.** Descriptive statistics of variables.

| VarName | Obs | Mean | SD | Min | Median | Max |
|---|---|---|---|---|---|---|
| TFPCH | 1896 | −0.578 | 13.427 | −84.738 | −0.075 | 77.372 |
| TECH | 1896 | −0.269 | 12.930 | −73.366 | −0.054 | 79.682 |
| TECCH | 1896 | −0.118 | 0.556 | −4.105 | 0.000 | 0.801 |
| x | 1896 | 0.360 | 1.577 | −4.605 | 0.658 | 2.679 |
| pgdp | 1896 | 0.999 | 0.767 | −0.736 | 1.069 | 2.558 |
| struc | 1896 | 14.084 | 8.371 | 1.640 | 12.400 | 36.000 |
| fdi | 1896 | 8.855 | 1.938 | 4.094 | 9.108 | 12.079 |
| gov | 1896 | 14.044 | 0.923 | 11.994 | 14.170 | 15.639 |
| patent | 1896 | 5.840 | 1.545 | 2.565 | 5.857 | 9.041 |
| R&D | 1896 | 0.021 | 0.054 | 0.000 | 0.010 | 0.910 |

## 4. Empirical Results

### *4.1. OLS Findings*

#### 4.1.1. Collinearity Test

The paper first conducts a systematic test for potential multicollinearity issues in the model to ensure the independence of the explanatory variables and enhance the robustness of the regression results. The multicollinearity test is not only an important part of the model construction process, but also assists the researcher in screening out the key explanatory variables to avoid the interference of redundant variables on the model performance, resulting in the better explanatory power and predictive ability of the model. Specifically, the multicollinearity test evaluates the degree of co-variance by calculating the variance inflation factor (VIF), which represents the ratio of the variance of the regression coefficients of the variables. The larger the value of VIF is, the more serious the problem of multicollinearity exists. Meanwhile, the inverse of VIF (i.e., tolerance) can also be used as another important indicator of covariance. When $0 < \text{VIF} < 10$, it can be assumed that there is no multicollinearity between the variables; when $10 \leq \text{VIF} < 100$, it indicates the existence of strong multicollinearity; when $\text{VIF} \geq 100$, it indicates that the problem of multicollinearity is very serious, which may seriously affect the credibility of the regression results.

In this paper, the core explanatory variables and control variables were analyzed by VIF in the constructed regression model. The test results are shown in Table 2, the VIF value of each variable is less than 10, indicating that there is no significant multicollinearity problem among the indicators selected in this paper.

In summary, from a statistical point of view, the independence between the variables in this study has been fully verified. This not only reduces the risk of possible interference of multiple covariance on the regression analysis, but also lays a solid foundation for the robustness of the subsequent analysis results. At the same time, the test results further enhance the model's ability to explain the relationship between the control factors and the primary explanatory variables, providing the credibility of the empirical test results.

**Table 2.** Collinearity test.

| | VIF | 1/VIF |
|---|---|---|
| patent | 3.602 | 0.278 |
| gov | 2.845 | 0.351 |
| pgdp | 2.566 | 0.39 |
| struc | 1.846 | 0.542 |
| fdi | 1.663 | 0.601 |
| x | 1.176 | 0.85 |
| Mean VIF | 2.283 | |

Variance inflation factor.

#### 4.1.2. Hausman and F-Tests for Model Fitting

Choosing an appropriate model is a crucial step in panel data analysis to guarantee the precision of the empirical findings. Common panel data models include mixed-effects models, fixed-effects models, and random-effects models, and the selection of different models depends on data characteristics and research objectives. In order to statistically determine the type of model applicable to the data, this paper combines theoretical and empirical tests by the Hausman test and *F* Test as the basis for determination. Hausman test is used to judge the choice between the fixed-effects model and the random-effects model, and its null hypothesis is that the random-effects model is more suitable, i.e., there is no correlation between individual effects and explanatory variables. If the test result significantly rejects the null hypothesis, it indicates that the fixed effects model is able to more accurately reflect the characteristics of the data because it allows for correlation between individual effects and explanatory variables. Meanwhile, the *F*-test is used to choose between the fixed-effects model and the mixed-effects model, with the null hypothesis that the mixed-effects model is more suitable for data analysis, i.e., the intercept term is the same for all individuals. If the test results significantly reject the null hypothesis, it indicates that the fixed effects model is more advantageous in capturing inter-individual heterogeneity. The test results in Table 3 show that the Hausmann test statistics are significant, rejecting the null hypothesis of a random effects model and supporting a fixed effects model.

**Table 3.** Hausman and *F*-tests: model fitting test.

| **Hausman Test** | | | ***F* Test** | | |
|---|---|---|---|---|---|
| **Chi$^2$ Statistic** | ***p* Value** | **Result** | **Chi$^2$ Statistic** | ***p* Value** | **Result** |
| 9.45 | 0.092 | reject | 0.82 | 0.905 | reject |

In summary, based on the combined analysis of the Hausman test and *F*-test, this paper chooses the fixed-effects model as the main analytical tool. This decision fully supports the acceptable characterization of the data and reliable fitness for the purpose of the model for the subsequent regression analysis, and the credibility and rigor of the empirical results.

#### 4.1.3. Benchmark Regression

In order to address the possible endogeneity of individual and time effects, it was indicated that this study should use a fixed-effects model for the regression analyses. In order to further improve the robustness and credibility of the findings, this study adopted the stepwise regression method to test the hypotheses. The stepwise regression method not only ensures a more detailed examination of variable relationships but also minimizes potential bias by systematically incorporating additional control variables. This approach enhances the interpretability and reliability of the results and provides strong empirical evidence for the hypotheses.

The first column of Table 4 represents the core explanatory variable *x* (NRD) showing a statistically significant positive correlation with the dependent variable (TFPCH) at the 1% significance level without the inclusion of control variables. In the third column of Table 4, which shows the case when all the control variables are added, NRD remains positively correlated with the index of change in TFPCH with a coefficient of 5.7269, which is significant at the 1% level of significance, indicating that all the others being constant, for every unit increase in NRD, TFPCH increases by an average of 5.7269 units. The empirical analyses show that NRD has a significant positive effect on the TFPCH, indicating that NRD has a positive effect on promoting the sustainable development of resource-based cities. This conclusion is consistent with the findings of Liu et al. [44], Lee and He [31], and Cheng et al. [45] in accepting Hypothesis 1. The theoretical underpinnings of this argument can be traced as far back as Adam Smith's book *The Wealth of Nations*, where the author argued that countries rich in natural resources could utilize these resources to create wealth for the nation to become the main driver of prosperity. Building on this idea, a range of scholars have further found that natural resource-rich countries tend to have higher levels of economic performance than resource-poor countries [46,47]. This view affirms the potential advantages of resource wealth. Cities with high resource dependence have enabled them to accumulate a great deal of technical experience and skills in the extraction, processing, and utilization of resources. Over time, these cities have been able to gradually increase the technical efficiency of the production process, i.e., achieving more output with the current level of technology unchanged. This increase in technical efficiency directly contributes to TFPCH growth. Thus, although these cities are highly resource-dependent, they are able to compensate to some extent for the negative effects of NRD through improvements in production efficiency.

**Table 4.** Benchmark regression.

| | (1) | (2) | (3) |
|---|---|---|---|
| **VARIABLES** | **TFPCH** | **TFPCH** | **TFPCH** |
| x | 21.9775 *** | 6.8673 *** | 5.7269 *** |
| | (24.71) | (5.94) | (4.85) |
| pgdp | | 0.0429 *** | 0.1235 *** |
| | | (4.59) | (7.47) |
| struc | | −0.0035 ** | −0.0008 |
| | | (−2.27) | (−0.50) |
| fdi | | | −0.0135 *** |
| | | | (−3.13) |
| gov | | | −0.0369 ** |
| | | | (−2.50) |
| patent | | | −0.0061 |
| | | | (−0.70) |
| Constant | −0.2732 *** | −0.0446 | 0.5502 *** |
| | (−7.36) | (−0.80) | (2.96) |
| Observations | 1896 | 1896 | 1896 |
| R-squared | 0.470 | 0.374 | 0.380 |
| area | YES | YES | YES |
| year | YES | YES | YES |

t-statistics in parentheses, *** $p < 0.01$, and ** $p < 0.05$.

To analyze the impact of the control variables, this research first evaluates the role of GDP per capita. The regression results show that GDP per capita (PGDP) as a control variable has a significant positive effect on TFP in resource-based cities. Its regression coefficient is 0.1235 and passes the statistical test at a 1% significance level, implying that

economic development plays a positive role in promoting TFP in resource cities. Economic growth is usually accompanied by the optimization of industrial structure, technological progress, and capital accumulation, which help to improve production efficiency and thus promote the sustainable development of resource cities. In addition, the authors of [48] also suggest that rising income levels lead residents to pay more attention to quality of life and increase their awareness of environmental protection, a process that helps to promote urban TFPCH. Overall, economic development not only promotes the industrial upgrading and innovation ability of resource-based cities, but also lays a solid foundation for their qualitative or sustainable development.

However, it is noteworthy that not all the control variables exhibit a positive effect. Governance by the government (gov) as a control variable has a negative coefficient in the regression model at the 5% significance level, indicating that governance by the government is significantly and negatively related to the TFPCH. This result generally suggests that excessive local government intervention in resource-based cities and inefficiencies in fiscal expenditures are impediments to the high-quality development of these cities. Therefore, it is particularly important to reassess the sustainability of government interventions in resource-based cities. The regional economic growth in China inevitably needs to consider the far-reaching impact of local governments' fiscal instruments on the regional economy. If there is an imbalance in governance between the government and the market, entrepreneurs may reduce their innovative behavior in favor of unproductive rent-seeking activities in order to reap excess profits through unfair means [49]. In addition, since natural resources are relatively easy to access in resource-based cities, this resource advantage may trigger the exchange of resources for short-term economic benefits, with the sacrifice of long-term governance by the moral hazard such as bribing government officials [50]. This poor governance model further inhibits economic transformation and high-quality development in resource-based cities.

Similarly, the control variable foreign direct investment (fdi) also exhibits a significantly negative effect at the 1% significance level, with a coefficient of −0.0135. This indicates that FDI negatively impacts TFPCH in resource-based cities. One possible explanation for this result is the "FDI crowding-out effect", where foreign investments in resource-based cities may predominantly flow into capital-intensive or extractive industries rather than high-tech or innovation-driven sectors, thereby limiting technological spillovers and productivity gains. In addition, in China's resource-based cities, most of the resource-related industries are dominated by state-owned enterprises (SOEs), whether they are resource development or exploration industries. A variety of reasons, such as strong government control and high policy sensitivity, have led to foreign firms facing high barriers entering these industries. Even when foreign investment enters, it is often only able to operate in the downstream or non-core areas of the supply chain, making it difficult to make a substantial contribution to technological innovation and efficiency improvement in the industry as a whole. Finally, we can see that (patent) and (struc) are not statistically significant, indicating that they do not substantially impact TFPCH in resource-based cities. This can be explained as follows. First, innovation (measured by patents) may have a lagged effect. While patents reflect the frequency of innovation activities, it takes time for these innovations to translate into productivity gains, meaning the relationship between innovation and TFPCH may not be significant in the short term. Additionally, resource-based cities are often dominated by resource-intensive industries, and the restructuring of their legacy structure is a very challenging process. Therefore, the adjustment of industrial structure and its impact on TFPCH may not be strong enough, resulting in the insignificance of this variable in the regression analysis.

This empirical finding highlights the need to reassess the governance strategies of the government to ensure that their objectives are aligned with sustainable ways. Relying on the top-down approach to governance may entrench resource dependence and slow down the transition of these cities to a more diversified and sustainable structure. In order to promote high-quality development in resource-based cities, governments need to shift from "controlling governance" to "facilitating governance". For example, governments can build a stronger innovation base for resource-dependent cities and optimize the efficiency of resource use through field-oriented customized policies for R&D. By adjusting governance models to reduce the negative impacts of resource dependence and encouraging market-driven innovation activities, resource-dependent cities can not only escape their current development dilemmas but also achieve long-term sustainable development.

#### 4.1.4. Heterogeneity Analysis

Based on the regression analysis as discussed above, our research will analyze the mechanism of resource dependence on the TFPCH at this second stage. For this purpose, we will carry out a heterogeneity analysis to explore in-depth the differential impacts of resource dependence on technological efficiency, technological advancement, and the stage of urban development. The heterogeneity analysis is aimed to reveal more precisely the specific path and characteristics of the resource dependence on TFPCH. The analysis is carried out in three parts. First, we will decompose TFPCH with technical efficiency and technological progress separately, in order to clarify through which part of resource dependence mainly affects the change in TFPCH. Second, based on the classification criteria of the National Sustainable Development Plan for Resource-based Cities (2013–2020), issued by the State Council, resource-based cities will be grouped according to their development stages (growth, maturity, decline, and regeneration) to analyze the differentiated roles of resource dependence at the different development stages. Specifically, the growth stage is characterized by rapid resource exploitation, with resource industries serving as the primary driver of economic development. During this phase, industrial diversification remains limited, and economic growth heavily depends on resource extraction. In the maturity stage, resource development stabilizes, and the industrial structure becomes more established. However, a high reliance on resources persists, and the need for economic transformation gradually becomes apparent. The decline stage is marked by resource depletion, leading to a slowdown in economic growth. The industrial structure remains highly specialized, lacking diversification, making economic transformation and industrial restructuring imperative. In the regeneration stage, cities actively pursue industrial upgrading and economic diversification through technological innovation, ecological restoration, and the development of emerging industries, with the objective of achieving long-term sustainable growth. This classification is based on the National Sustainable Development Plan for Resource-based Cities (2013–2020), which was introduced in 2013 with a seven-year implementation period. The plan aims to guide and support the sustainable development and transformation of China's resource-based cities by addressing challenges related to resource dependence, economic restructuring, and environmental sustainability. Third, according to the criteria of the Macroeconomic Research Institute of the State Planning Commission, this paper will classify cities based on natural resource types (oil, coal, natural gas, minerals, nonferrous metals, and others), and explore the heterogeneous effects of different resource types on the change in TFPCH. This analysis will shed light on the role of NRD from the perspective of resource types, which fills the gap in the existing research, showing the major contribution of this paper.

Given the large diversity of production technologies among provinces and cities, it is more appropriate to use a non-parametric method to measure TFPCH. Since the imposition

of a uniform production function form may lead to bias in its implications, this paper treats all our DMUs independently and uses the Malmquist index to measure and compare TFPCH. To further reveal the driving factors of TFPCH, this paper uses the Malmquist index decomposition into the index of technical efficiency change (TECH) and the index of technological progress (TECCH). These two sub-indices will be separately examined for the specific paths of the variable x's effect on TFPCH. Based on the regression results in Table 5, when the dependent variable is TECH, the variable *x* shows a positive correlation with TECH at the 1% level of statistical significance. This suggests that *x* primarily promotes the growth of TFPCH by enhancing technical efficiency. This finding suggests that the improvement in technical efficiency may stem from the improvement in resource allocation or the optimization of the management, as the path for the improvement in TFPCH. In contrast, when the dependent variable is TECCH, although the coefficient of *x* is positive, it is not statistically significant. This suggests that *x* has a weak effect on technological progress and fails to significantly drive technological innovation or breakthroughs. This result reveals the possible contradiction in the choice of development paths for resource-based regions; in the short term, relying on the efficient use of resources and/or managerial optimization can drive economic growth, but in the long term, insufficient technological progress may lead to insufficient development momentum for sustainable development.

**Table 5.** Heterogeneity analysis on production technology.

| | **Technical Efficiency** | **Technological Progress** |
|---|---|---|
| **VARIABLES** | **(TECH)** | **(TECCH)** |
| x | 0.0463 *** | 0.0001 |
| | (3.78) | (0.44) |
| pgdp | 0.2579 *** | −0.0025 *** |
| | (9.18) | (−3.95) |
| struc | −0.0097 *** | −0.0000 |
| | (−3.74) | (−0.52) |
| fdi | −0.0065 | −0.0003 * |
| | (−0.89) | (−1.73) |
| gov | −0.1967 *** | −0.0014 ** |
| | (−7.88) | (−2.42) |
| patent | −0.0297 ** | 0.0019 *** |
| | (−2.01) | (5.63) |
| Constant | 2.8957 *** | 0.0145 ** |
| | (9.29) | (2.03) |
| Observations | 1896 | 1895 |
| R-squared | 0.372 | 0.941 |
| area | YES | YES |
| year | YES | YES |

t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

To further promote productivity growth, policymakers should give priority attention to technological progress rather than simple technological efficiency. The promotion policies should focus on creating more favorable conditions for technological progress through enhanced investment in R&D and technology transfer mechanisms. Through these comprehensive initiatives, resource-based regions are expected to break away from the shackles of traditional resource dependence and achieve sustainable economic growth. In conclusion, the empirical analyses in this paper not only verify the key role of the TECH path in TFP growth but also provide important insights for resource-dependent regions to achieve high-quality sustainable development.

In order to explore the differentiated role of resource dependence on the TFPCH at different development stages, this paper classifies resource-based cities into growth, maturity, decline, and regeneration groups based on their development stages. The significance of this categorization lies in the fact that resource-based cities can be captured by their differentiated stages of development resulting from the obvious differences in development patterns and policy needs. Through categorical analysis, it can provide a basis for the development of more precise and appropriate land development policies.

From the regression results in Table 6, there exists significant heterogeneity in the effect of resource dependence on TFPCH at different stages of development. In the growing and regenerating urbanization stage, resource dependence is positively associated with the change in TFPCH and it is significant at a 1% significance level. This suggests that resource-based cities in these two stages developed a better performing system of resource utilization and management, with higher efficiency on resource allocation and thus higher technical efficiency. As an exemplary case among the growing cities, Ordos City in Inner Mongolia is represented by its proactive resource exploitation as the core driver of economic growth. Abundant energy resources have kept its economy in a high growth mode, and the contribution of the resource industry to the land development maintained at a significant level. Ordos has also promoted R&D investment and green transformation in recent years in an attempt to further explore sustainable development, resulting in much better performance of the local economy. Regenerating cities, such as Luoyang City in Henan Province and Tangshan City in Hebei Province, have largely shifted away from their high dependence on resources toward diverse economic and social development with a focus on the technological innovation capacity. On the contrary, declining cities such as Jingdezhen City in Jiangxi Province, are facing serious challenges coming from depleting resources and lagging economic development. In contrast, mature cities, such as Datong in Shanxi, have entered a relatively stable stage of development. The growth rate of resource-dependent industry has decreased, and thus the impact of resource dependence on TFPCH is gradually weakening, resulting in the lack of statistical significance on the regression.

**Table 6.** Heterogeneity analysis on the stage of economic development.

| | **Growth Stages** | **Maturity Stages** | **Decline Stages** | **Regeneration Stages** |
|---|---|---|---|---|
| **VARIABLES** | **TFPCH** | **TFPCH** | **TFPCH** | **TFPCH** |
| x | 30.2513 *** | −1.6287 | 0.0551 ** | 13.3405 *** |
| | (6.34) | (−0.84) | (2.15) | (5.33) |
| pgdp | −0.1264 * | −0.0300 | 0.4232 *** | 0.1883 *** |
| | (−1.87) | (−1.30) | (5.10) | (4.57) |
| struc | −0.0817 *** | 0.0010 | 0.0359 *** | −0.0007 |
| | (−9.97) | (0.42) | (7.83) | (−0.11) |
| fdi | −0.0952 *** | −0.0094 | −0.0160 | −0.0155 |
| | (−5.42) | (−1.46) | (−1.34) | (−1.56) |
| gov | −0.0970 | 0.0551 ** | −0.4124 *** | −0.1310 *** |
| | (−1.55) | (2.33) | (−6.85) | (−3.70) |
| patent | 0.0951 *** | −0.0211 | 0.0753 *** | 0.0448 ** |
| | (2.98) | (−1.44) | (3.46) | (2.47) |
| Constant | 2.2764 *** | −0.6045 ** | 4.2148 *** | 1.5598 *** |
| | (3.00) | (−2.08) | (5.78) | (3.42) |
| Observations | 236 | 1016 | 387 | 253 |
| R-squared | 0.954 | 1.000 | 1.000 | 0.996 |
| area | YES | YES | YES | YES |
| year | YES | YES | YES | YES |

t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

To summarize, China has a large number of resource-based cities with significant differences in resource endowment, different levels of economic and social development,

and different intrinsic problems. Therefore, the key path to promote the high-quality development of resource cities is to tailor the policy measures to the local conditions. For cities at different stages of development, differentiated policy measures should be adopted to achieve stronger governance.

Having analyzed the impact of different stages of development (growth, maturity, decline, and regeneration) on TFPCH, we will evaluate the source of differences in the different resource types (oil, coal, natural gas, minerals, non-ferrous metals, etc.) to propose the more comprehensive role of NRD in sustainable development.

As shown in Table 7, diverse types of resources such as oil, coal, minerals, non-ferrous metals, and other resources are all significant, with the exception of natural gas, at least at a 10% level with positive coefficients, suggesting that these resources positively affect TFPCH growth to some extent. This result shows the very insightful implications in several ways. First, resources such as oil, coal, minerals, and non-ferrous metals are often accompanied by well-established industrial chains, such as extraction, processing, smelting, and manufacturing. The exploitation of resources not only contributes directly to the resource-extracting industry, but also to the related industries. For example, coal-rich cities usually promote more complicated energy supply chains, resulting in a more enhanced TFPCH in general. Second, resource-based industries often generate considerable fiscal revenues for the local economy, which in turn support infrastructure construction and R&D investment in other related industries. Such fiscal support can promote technological progress and labor productivity, enhancing the long-term growth potential of the local economy. Finally, traditional mineral resource cities are often supported by national policies, such as special subsidies and tax incentives, to promote the efficient use of resources and the sustainable development of industries. From a comprehensive perspective, resources such as oil, coal, minerals, and non-ferrous metals have a more obvious role in promoting TFPCH, mainly due to their longer industrial chain, strong driving effect, larger financial contribution, and higher policy support. Natural gas, on the other hand, fails to show a statistically significant impact due to its relatively short industry chain, long development cycle, and imperfect market mechanism.

**Table 7.** Heterogeneity analysis on the resource types.

| | **Oil** | **Coal** | **Natural Gas** | **Minerals** | **Non-Ferrous Metals** | **Other Resources** |
|---|---|---|---|---|---|---|
| **VARIABLES** | **TFPCH** | **TFPCH** | **TFPCH** | **TFPCH** | **TFPCH** | **TFPCH** |
| x | 22.4980 *** | 7.7389 *** | −11.6921 | 11.1486 *** | 0.1495 *** | 9.2863 * |
| | (3.71) | (4.41) | (−1.31) | (5.74) | (8.02) | (1.76) |
| pgdp | 0.0499 * | 0.0457 *** | −0.0253 | 0.1665 *** | 0.8325 *** | 0.4196 *** |
| | (1.92) | (3.11) | (−0.12) | (5.77) | (13.84) | (3.22) |
| struc | −0.0940 *** | 0.0090 *** | −0.0622 *** | −0.0067 ** | 0.0119 *** | −0.0308 *** |
| | (−11.39) | (5.27) | (−4.39) | (−2.36) | (3.03) | (−4.40) |
| fdi | −0.0465 *** | 0.0259 *** | −0.0328 | −0.0218 *** | 0.0178 ** | −0.0803 *** |
| | (−7.11) | (5.35) | (−1.03) | (−3.46) | (2.35) | (−4.09) |
| gov | −0.2096 *** | 0.0484 *** | −0.1102 | −0.0410 | −0.4939 *** | −0.3739 *** |
| | (−4.48) | (2.81) | (−0.75) | (−1.63) | (−15.90) | (−4.35) |
| patent | 0.1923 *** | −0.0403 *** | −0.1380 ** | −0.0240 * | −0.0390 ** | 0.0587 |
| | (8.70) | (−3.96) | (−2.29) | (−1.87) | (−2.49) | (1.65) |
| Constant | 3.5209 *** | −1.0323 *** | 3.7284 * | 0.7965 ** | 6.0296 *** | 5.5910 *** |
| | (4.95) | (−4.86) | (1.99) | (2.59) | (17.30) | (5.25) |
| Observations | 118 | 728 | 101 | 491 | 135 | 321 |
| R-squared | 1.000 | 1.000 | 0.824 | 1.000 | 1.000 | 0.907 |
| area | YES | YES | YES | YES | YES | YES |
| year | YES | YES | YES | YES | YES | YES |

t-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

### 4.2. Moderating Effect

The heterogeneity analysis in the previous section explored the impact of NRD on the index of TFPCH in terms of three dimensions: the technological decomposition, the different stages of development, and the type of resources. However, focusing on the direct impact of resource dependence, it is difficult to fully reveal the underlying mechanism. In order to further clarify the path of influence, it is necessary to introduce moderating variables to examine how external factors regulate the relationship between NRD and the TFPCH in resource-based cities.

Given the strategic focus on innovation-driven development, R&D intensity is selected as a moderating variable in this study. R&D intensity refers to the commitment to innovation and the willingness to allocate resources to R&D activities. Traditionally, R&D intensity has been mainly used in firm-level studies, usually measured as the share of R&D expenditures in firms' revenues [51,52], while studies on the regional or city level are limited. In this paper, we will use the share of R&D expenditures in regional GDP to measure regional R&D intensity in order to assess its moderating role in the dynamic impact of NRD on TFPCH. This approach will provide a new analytical perspective for understanding the innovation-driven development of resource-based cities. The empirical results in Table 8 indicate that the interaction term between R&D intensity and the key explanatory variable (NRD) is significant at a 1% level, with a positive coefficient. This suggests that R&D intensity plays a positive moderating role in the relationship between resource dependence and the TFPCH. In other words, higher R&D enhances the productivity gains associated with resource dependence, further promoting the sustainable development of resource-based cities. Specifically, an increase in R&D, as measured by the number of patents, significantly increases the level of TFPCH. Thus, our research accepts Hypothesis 2. The findings further suggest that R&D is an important driver for resource-based cities to achieve sustainable development. A study by [53] points out that the impact of natural resources on the regional economy does not directly but indirectly promote high-quality economic development by enhancing the level of innovation. Based on this viewpoint, this paper argues that R&D intensity, as a moderating variable, has helped resource-dependent cities to achieve a positive impact on the TFPCH. In order to achieve a higher level of sustainable development in resource-based cities, therefore, it is necessary to increase R&D. Increasing R&D plays a crucial role in stimulating innovation and addressing the challenges posed by resource dependence, such as stagnant economic recession and over-reliance on resource extraction industries. By boosting R&D, resource-based cities can shift toward more diversified, resilient economies. R&D brings both immediate economic benefits and aligns with long-term goals of sustainable development. As resource-dependent cities embrace innovation-driven growth, they can break away from traditional development pitfalls and move toward more expandable and sustainable economic structures. The integration of advanced technologies into production processes not only alleviates environmental burdens but also optimizes resource consumption and strengthens economic resilience. Since we found the heterogeneous character of NRD impact in Section 4.1, policymakers should implement more field-oriented differentiated measures to effectively incentivize R&D, encourage collaboration between research institutions and industries, and strengthen the capacity for technological innovation. These efforts will help transform resource advantages into key drivers for the sustainable development of resource-based cities.

**Table 8.** Moderating effect of R&D.

| | (1) |
|---|---|
| **VARIABLES** | **TFPCH** |
| x | 4.9087 *** |
| | (4.01) |
| inter | 0.0155 *** |
| | (5.02) |
| sci | −0.0377 *** |
| | (−7.21) |
| pgdp | 0.1058 *** |
| | (6.41) |
| struc | 0.0013 |
| | (0.84) |
| fdi | −0.0145 *** |
| | (−3.38) |
| gov | −0.0048 |
| | (−0.33) |
| patent | −0.0153 * |
| | (−1.76) |
| Constant | 0.1394 |
| | (0.75) |
| Observations | 1896 |
| R-squared | 0.406 |
| area | YES |
| year | YES |

t-statistics in parentheses, *** $p < 0.01$, and * $p < 0.1$.

### *4.3. Endogeneity Test*

Due to the lack of sufficient attention to the potential endogeneity issues, there are some contradictions between RB and RC. To clarify this issue, this paper adopts the generalized moment estimation (GMM) method for parameter estimation and further introduces the more efficient systematic GMM and differential GMM approaches to solve the potential endogeneity issue, and thus to improve the reliability of the results. According to the empirical results in Table 9, it can be seen from the AR sequential autocorrelation test that the perturbation terms do not have second or higher-order autocorrelation, which satisfies the basic preconditioning assumptions of GMM regression. In addition, Hansen's over-identification test accepts the original hypothesis of "*all instrumental variables are valid*", which further verifies the applicability of the model, indicating that the instrumental variables used in this paper are reasonable and valid. The regression results show that the core variable *x* is significant at a 1% significance level under both systematic GMM and differential GMM methods, implying that resource dependence has a positive effect on TFP. Meanwhile, this paper finds a very interesting phenomenon; the coefficient of the first-order lag term of the TFPCH is −0.0238 and it is significant at a 5% significance level. The findings indicate that the TFPCH index in China's resource-based cities exhibits a fluctuating pattern. Generally, the coefficient of the first-order lagged dependent variable falls between 0 and 1. However, when estimated using the DIF-GMM method, the first-order lagged coefficient of the TFPCH is found to be negative. This suggests that a higher TFP index in the previous period is followed by a decline in the current period. However, this decline creates room for future improvement, distinguishing this cyclical volatility from the inertia effect commonly observed in most economic variables. This periodic fluctuation can be explained by China's political promotion system. Local officials tend to prioritize economic indicators, particularly GDP growth, as a key metric for career advancement. In contrast, high-quality economic development requires substantial upfront

investment, but does not yield immediate results. It often takes a secondary role due to the lack of short-term incentives. Only when the central government conducts inspections or emphasizes specific policy priorities, do sustainability-related initiatives receive greater attention. As a result, high-quality economic development in China is characterized by intermittent progress rather than steady advancement, making such volatility a common occurrence.

**Table 9.** Endogeneity test.

| | **SYS-GMM** | **DIF-GMM** |
|---|---|---|
| **VARIABLES** | **TFPCH** | **TFPCH** |
| L.TFPCH | 0.0135 * | −0.0238 ** |
| | (1.89) | (−2.20) |
| x | 15.8760 *** | 36.5320 *** |
| | (5.38) | (8.42) |
| pgdp | −65.5793 *** | −81.9770 *** |
| | (−3.69) | (−4.01) |
| struc | 1.5548 ** | 3.8825 *** |
| | (2.53) | (5.39) |
| fdi | −59.3969 *** | −54.3271 *** |
| | (−15.43) | (−12.12) |
| gov | 110.5700 *** | 112.5334 *** |
| | (8.02) | (7.30) |
| patent | 36.3787 *** | 44.3159 *** |
| | (15.22) | (14.87) |
| Constant | −1204.1216 *** | −1345.4361 *** |
| | (−7.99) | (−7.84) |
| Observations | 1676 | 1676 |
| Number of id | 112 | 112 |
| AR1 | 0.070 | 0.063 |
| AR2 | 0.352 | 0.417 |
| Hansen | 0.741 | 0.818 |

z-statistics in parentheses, *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

In summary, the positive effect of resource dependence on TFP is verified again through the empirical analysis of systematic GMM and differential GMM methods. Meanwhile, the endogeneity test results of this paper show that the model and its instrumental variable selection are reasonable and effective, which further enhances the reliability and robustness of the research conclusions.

### *4.4. Robustness Test*

Based on the endogeneity test on the rationality of the model's instrumental variable selection and the robustness of the results, this paper carries out a robustness test in this section to further enhance the reliability of the research conclusions. The robustness test aims to verify whether the significance and directionality of the core explanatory variables remain consistent through different methods so as to ensure the solidity and general applicability of the empirical findings.

The exclusion of exceptional years (outliers) is a common approach in robustness testing, aiming to exclude time periods that may have an abnormal effect on the results. The time span of the sample selected for this study covers the year 2020 and beyond, and the 2020 outbreak of COVID-19 was a sudden health public event that profoundly affected the globe, with unprecedented impacts on economic performance and social development. For resource-based cities in particular, the external shocks from COVID-19 can be viewed as strictly exogenous disruptive factors. Such exogenous events may interfere with the

relationship between NRD and TFPCH through multiple and complex pathways. Ignoring this factor may lead to the problem of omitted variables in the model, further affecting the accuracy of parameter estimation. For this reason, this paper excludes the samples of special years in 2020 and after, and re-conducts a regression analysis of the model. After excluding the special years, this paper carries out a sample sensitivity analysis to verify the robustness of the research findings under different sample choices. If the significance and directionality of the core explanatory variables remain consistent with the previous paper after excluding the special samples, the empirical results of this paper are highly robust. Through this method, not only can we effectively control the disturbance caused by the new global epidemic but also verify whether the impact of resource dependence on TFP is universally applicable. The empirical results are shown in Table 10, where the dependent variable $x$ is positively correlated with the independent variable at a 1% significance level regardless of the inclusion of control variables. Therefore, it is verified that NRD has a positive effect on the TFPCH.

**Table 10.** Robustness test with outliers of COVID-19.

| | **Excluding the Effects of the COVID-19** |
|---|---|
| **VARIABLES** | **TFPCH** |
| x | 3.4710 *** |
| | (2.82) |
| pgdp | 0.1157 *** |
| | (6.36) |
| struc | −0.0012 |
| | (−0.64) |
| fdi | −0.0156 *** |
| | (−3.48) |
| gov | −0.0222 |
| | (−1.31) |
| patent | −0.0166 * |
| | (−1.79) |
| Constant | 0.4118 * |
| | (1.89) |
| Observations | 1788 |
| R-squared | 0.375 |
| area | YES |
| year | YES |

t-statistics in parentheses, *** $p < 0.01$, and * $p < 0.1$.

In order to further verify the reliability of the results and exclude estimation errors triggered by the choice of methodology, this paper conducts a second robustness test, i.e., the analysis is re-run by replacing the estimation method. In this part, the Pooled Ordinary Least Squares (POLS) method is used as the estimation tool to revalidate the relationship between the core explanatory variable NRD and the TFPCH. Mixed Least Squares is a basic and widely used regression method whose main advantage lies in its intuitive calculation process and its ability to provide test results for the overall trend by treating all the samples without grouping. The introduction of this method not only reduces the impact of potential model-setting bias but also provides comparative validation of the GMM results in the previous section, further enhancing the robustness of the conclusions.

According to the regression results in Table 11, the regression coefficients of the core explanatory variable resource dependence ($x$) are always positive and significant at a significance level of 1%, regardless of the inclusion of control variables. This result is consistent with the previous findings using generalized moments estimation and provides

further evidence that NRD has a significant positive effect on the TFPCH. This suggests that the results remain highly reliable and robust even after changing the estimation method.

**Table 11.** Robustness test with methodology.

| VARIABLES | POLS TFPCH | POLS TFPCH |
|---|---|---|
| x | 0.0475 *** | 0.0464 *** |
| | (2.79) | (3.40) |
| pgdp | | −0.0110 |
| | | (−1.00) |
| struc | | −0.0041 *** |
| | | (−4.76) |
| fdi | | −0.0053 |
| | | (−1.53) |
| gov | | 0.0289 *** |
| | | (2.99) |
| patent | | −0.0078 |
| | | (−1.20) |
| Constant | −0.1186 *** | −0.3171 *** |
| | (−17.34) | (−2.83) |
| Observations | 1895 | 1895 |
| R-squared | 0.152 | 0.153 |
| area | NO | NO |
| year | NO | NO |

t-statistics in parentheses, *** $p < 0.01$.

## 5. Discussion and Suggestions

Based on the data from 112 resource-based cities in China from 2003 to 2021, this research evaluated the TFPCH of each city using the Super-SBM-DEA-Malmquist index method and further analyzed the effect of resource dependence on the TFP change. The empirical results show that NRD has a significant positive effect on the TFP change index of resource-based cities, which supports the applicability of the 'resource blessing (RB)' hypothesis in China. These findings align with previous studies suggesting that resource endowments can serve as a driver of economic growth under certain conditions. In order to find out the missing links on certain conditions of RB, the moderating effect and heterogeneity analyses further reveal the mechanism of resource dependence on TFP and its differences in different contexts.

Specifically, R&D intensity, as a moderating variable, significantly and positively affects the role of resource dependence on the TFP change, suggesting that increasing R&D contributes to the sustainable development of resource-based cities. It is noteworthy, however, that the advantage conferred by natural resource endowment is inherently unsustainable. As non-renewable resources have gradually depleted, the economic growth rate of resource-based cities will inevitably decelerate, potentially leading to development bottlenecks. Consequently, resource-based cities must urgently pursue economic transformation to achieve long-term sustainable development. In particular, the concept of sustainable development in this study primarily focuses on the balance between economic growth and environmental protection. While resource dependence may contribute to economic growth in the short term, the non-renewable nature of resources makes it unsustainable as a long-term development strategy. The reckless extraction of the resources may make worse for the land development as well. Over-reliance on resource extraction alone is insufficient to maintain sustainable land development. Therefore, achieving sustainable development requires resource-based cities to leverage technological innovation driven by

R&D, facilitating industrial transformation and reducing dependence on natural resources. By fostering continuous innovation-driven growth, resource-based cities can enhance their economic resilience and achieve sustainable and highly qualitative development in the long term.

However, there exists a pervasive deficiency in R&D investment among China's resource-based cities. According to the 2023 National Science and Technology Investment Statistics Bulletin, jointly released by the National Bureau of Statistics, the Ministry of Science and Technology, and the Ministry of Finance, China's total R&D expenditure surpassed CNY 3.3 trillion in 2023, with the national R&D investment intensity reaching 2.65%. In contrast, the R&D investment intensity in resource-based regions, exemplified by Heilongjiang province, stands at 1.44%, ranking only at a moderate level nationwide. This disparity underscores the insufficient momentum in technological innovation and industrial transformation within resource-based cities, with inadequate R&D posing a significant constraint on their ability to achieve sustainable and high-quality development.

Heterogeneity analyses show that TFPCH improvement stems mainly from technical efficiency rather than technological progress, emphasizing that innovation application is more crucial than R&D itself. This highlights governance gaps in technological innovation, as government-supported R&D often shows only superficial effects. Resource-based cities respond differently to the performance of NRD according to various development stages of growth, maturity, decline, and regeneration. The strongest positive impact on TFP growth is observed in growth and regeneration city groups, followed by a moderate effect in declining cities, while the impact on mature cities is statistically insignificant, indicating a need for more differentiated policy interventions on R&D activities.

One of the most important policy guidelines for the sustainable development of resource-based cities is the National Plan for the Sustainable Development of Resource-Based Cities. Based on the different stages of economic development level, the plan classifies resource-based cities into growth, maturity, decline, and regeneration groups, and formulates differentiated policy measures for different types of cities. This study shed light on this strategic framework by the heterogeneity analysis to find out the categorical field-oriented policies. The core of our research emphasizes technological innovation as a key driver of sustainable development, and thus advocates for increased R&D investment. Meanwhile, the 14th Five-Year Plan (2021–2025) further reinforces these development priorities and proposes a strategic transformation path for resource-based cities. Among the cities, industrial transformation has been put in a more prominent position for the local governments to reduce their reliance on traditional resource industries and to promote emerging industries such as new materials, renewable energy, digital economy, and so on. In addition, the national plan explicitly takes ecological restoration as one of the core objectives and proposes proactive initiatives to strengthen land reclamation, pollution control, and ecosystem refurbishment in response to the environmental degradation caused by resource extraction, so as to ensure the sustainable development of resource-based cities.

## 6. Conclusions

This paper analyzed in depth the opportunities and challenges of resource-based cities. Even if there are competitive advantages for the resource-based cities, it could not be sustainable in that its governance is very weak to promote sustainable performance based on innovation. Therefore, we may conclude our research with the following policy recommendations: First, resource-based cities should increase R&D to foster innovation-driven growth, facilitate industrial upgrading, and ensure long-term sustainability. Governments can play a pivotal role in this process by providing financial support, tax incentives, and dedicated research funds for enterprises and research institutions to strengthen technologi-

cal innovation, thereby transforming resource endowments into technological advantages. Second, governance structures should be optimized to minimize excessive administrative intervention, thereby stimulating market-driven innovation and strengthening the endogenous drivers of urban development. Third, more differentiated specific policies should be implemented according to the level of local economic development. For mature resource-based cities, policy efforts should prioritize industrial diversification and the advancement of high-value-added sectors, whereas for declining cities, targeted policy support should be reinforced to facilitate the economic transition and industrial upgrading. Fourth, resource-specific analyses should be conducted to assess the impact of different resource types on TFP growth. In particular, further research is needed to elucidate the mechanisms through which natural gas development influences productivity, enabling the formulation of more precise and effective industrial policies. Fifth, future policies should place greater emphasis on enhancing the endogenous dynamism of resource-based cities, refining government intervention mechanisms, and prioritizing R&D and innovation-driven development models.

Efforts should be made to integrate emerging resource-based cities into diversified urban economies, leveraging local resource endowments with the potential new field of emerging industries. Policymakers should encourage the development of public–private partnerships (PPP) tailored to local conditions and proactively support the establishment of customized resource-based land use planning. The government should implement more flexible and innovation-friendly policies for enterprises to reinforce sustainable land resource management. Sixth, given the growing importance of ecological transformation to ensure sustainable urban development, more specific consideration should be made for ecological restoration. Taking into account the unique characteristics of various resource-based cities across China, a more transparent and predictable ecological land use mission should be established, with an emphasis on strengthening ecological governance. Promoting urban sustainability through ecological transformation will not only facilitate the economic transition of resource-based cities toward a low-carbon economy, but also provide valuable policy insights for sustainable cooperation worldwide.

This study not only expands the perspective of total factor productivity research in resource-based cities but also provides new empirical support for the development model of resource-dependent economies. However, there are still some limitations in this study; for example, it fails to further distinguish the impact of different types of technological innovation on TFP, and thus future research could analyze this in more detail by combining patent data or firm-level innovation activities. In addition, the heterogeneity of resource cities under different institutional environments and market mechanisms can be further explored to provide a theoretical basis for more refined policy formulation.

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# Appendix A

**Table A1.** Classification of cities by region and province.

| Region | Province (No. of Cities) | Cities |
|---|---|---|
| Eastern | Hebei (5) | Zhangjiakou, Chengde, Tangshan, Xingtai, and Handan |
| | Liaoning (6) | Fuxin, Fushun, Benxi, Anshan, Panjin, and Huludao |
| | Zhejiang (1) | Huzhou |
| | Jiangsu (2) | Xuzhou and Suqian |
| | Fujian (3) | Nanping, Sanming, and Longyan |
| | Shandong (6) | Dongying, Zibo, Linyi, Zaozhuang, Jining, and Tai'an |
| | Guangdong (2) | Shaoguan and Yunfu |
| Central | Shanxi (10) | Datong, Shuozhou, Yangquan, Changzhi, Jincheng, Xinzhou, Jinzhong, Linfen, Yuncheng, and Lvliang |
| | Jilin (5) | Songyuan, Jilin, Liaoyuan, Tonghua, and Baishan |
| | Heilongjiang (8) | Heihe, Daqing, Yichun, Hegang, Shuangyashan, Qitaihe, Jixi, and Mudanjiang |
| | Anhui (8) | Suzhou, Huaibei, Huainan, Chuzhou, Ma'anshan, Tongling, Chizhou, and Xuancheng |
| | Jiangxi (5) | Jingdezhen, Xinyu, Pingxiang, Ganzhou, and Yichun |
| | Henan (7) | Sanmenxia, Luoyang, Jiaozuo, Hebi, Puyang, Pingdingshan, and Nanyang |
| | Hubei (2) | Ezhou and Huangshi |
| | Hunan (4) | Hengyang, Chenzhou, Shaoyang, and Loudi |
| Western | Inner Mongolia | Baotou, Wuhai, Chifeng, Hulunbuir, and Ordos |
| | Guangxi (3) | Baise, Hechi, and Hezhou |
| | Sichuan (8) | Guangyuan, Nanchong, Guang'an, Zigong, Luzhou, Panzhihua, Dazhou, and Ya'an |
| | Guizhou (2) | Liupanshui and Anshun |
| | Yunnan (5) | Qujing, Baoshan, Zhaotong, Lijiang, and Lincang |
| | Shaanxi (6) | Yan'an, Tongchuan, Weinan, Xianyang, Baoji, and Yulin |
| | Gansu (7) | Jinchang, Baiyin, Wuwei, Zhangye, Qingyang, Pingliang, and Longnan |
| | Ningxia (1) | Shizuishan |
| | Xinjiang (1) | Karamay |

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