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RESEARCH ARTICLE

How can China's coal cities achieve high-quality development?—An empirical study based on the "resource curse" hypothesis

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The relationship between the utilization of natural resources and high-quality economic growth has always been a concern of the academic community. China's coal cities to varying degrees suffer from population outflow, economic stagnation or even negative growth, precipitous drop in housing prices, serious environmental damage, and other problems. There is a negative correlation from the perspective of location between the enrichment of coal resources and economic development in China, confirming the existence of coal "resource curse" in China's interprovincial scope. Through establishing quantitative models. This article analyzes the transmission mechanism of the nonlinear impact of coal industry development on regional total factor productivity (TFP) from the 2 paths of industrial structure evolution and factor allocation efficiency. The sample panel data of 44 coal cities in China from 2003 to 2017 are examined to empirically test the impact of coal industry development in China's coal cities on TFP and its transmission mechanism. In the coal industry development, the service industry is being squeezed out to some degree, while the manufacturing industry is suffered from "double deindustrialization" and severe shrinkage. Such an industrial structure transformation is one of the transmission paths of "resource curse." The development of human capital (HC) and finance has a threshold effect on the impact of the coal industry development on the TFP of coal cities. The excessive growth of coal industry has a restraining effect on the development level of HC and finance that influences the efficiency of resource allocation, resulting in failure of such industries to promote the TFP. With the improvement of HC and finance sectors in coal cities, the development of coal industry has promoted the TFP. Therefore, this article holds that the government should aim at improving the efficiency of factor allocation, formulate scientific and reasonable industrial adjustment policies, upgrade industrial structure, and actively develop manufacturing and producer services. Meanwhile, in the process of coal city development, it should pay attention to improving HC input, actively develop green finance industry to promote the development of capital market, and promote the green transformation of coal industry. Actively develop new sources of energy. The sustainable development of coal cities should be guided according to different life cycle stages in order to achieve healthy and sustainable development and break the "resource curse."

Keywords: "Resource curse" hypothesis, Coal city, Industrial structure evolution, Human capital, Financial development

1. Introduction

The impact of natural resources on the efficiency of economic development has always been the focus of economists, but there are currently 2 distinct views on this issue in academia. Most early economists generally agreed on the positive impact of natural resources in economic development, viewing good natural resource endowments as the foundation of industrialization, and believing that abundant natural resources were the driving force for economic development, playing an important role in the process of regional economic takeoff. But from the 1960s, the economic development of many resource-oriented countries and regions often experienced a recession, corresponding to the astonishing speed of economic development in many countries with poor natural resources.

As a result, the academic community has conducted research on this unexpected phenomenon and further explored the relationship between natural resources and economic development. Researchers have found that excessive exploitation of natural resources may hinder regional economic development, while also causing a series of problems such as ecological deterioration,

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imbalance in industrial structure, and decline in institutional quality. Auty (1993) found that natural resource-rich countries often fail to use their resources effectively to promote economic growth over the longer term, and he defined the negative correlation between resource abundance and economic growth as a "resource curse." The resource curse may materialize, as opposed to a "resource blessing," through a country failing to use its resource-based income to diversify its larger economy with other productive or service industries and continuing to depend on the resource even under volatile global market conditions or changing social environments. The "resource curse" hypothesis sparked much debate and controversy among both scholars and policymakers about whether the resource curse actually exists, and under what conditions it may or may not happen.

On the question whether there is a "resource curse" in China, some scholars have argued that it does exist but other scholars have come to the opposite conclusion. Some scholars believe that the 2 views are not necessarily in complete opposition. The "resource curse" may only exist under certain conditions. The types of natural resources, the period of economic development and the influence of economic factors may all play a role in whether a resource curse develops. There are also differences in the role of economic development, so the hypothesis of "resource curse" is only a conclusion under specific conditions.

Shao et al. (2013) studied the impact of resource industry development on economic growth in 2 dimensions, gross national product (GDP) and total factor productivity (TFP), using a nonlinear threshold model. This classic research verified the existence of the "conditional resource curse" hypothesis. Damette and Seghir (2018) extended this concept; they found that the direct contribution of oil incomes to total output is rather positive, even if the magnitude of this effect is likely to decrease with the relative level of oil dependence. Weakening government efficiency is the main mechanism through which oil incomes lead to poor economic performances. Research in this area suggests that the impact of natural resources on economic growth has spatial heterogeneity, and different proxy variables can lead to different conclusions (Yu et al., 2022). The presence of a natural resource sector per se does not necessarily translate into worse development outcomes. The experience of a resource-rich country therefore varies to a significant extent (Savoia and Sen, 2021).

China has some of the richest coal resources in the world. The distribution pattern of coal in China is substantial in the north and west and poor in the south and east (Zeng et al., 2019). The distribution of coal reserves and the dislocation of economic development regions led to the transport pattern of western coal to the east and northern coal to the south. Between 2002 and 2012, China's coal industry experienced a golden decade, during which the booming economy was driven by an extensive pattern of growth, resulting in the emergence of "coal cities," or cities that came to be heavily dependent on coal mining and washing. These cities experienced an irreversible impact on their industrial structure and factor allocation efficiency—in other words, they were locked into the coal economy even more. When coal prices plummeted in 2013, their problems began surfacing.

Due to prevailing global technology and productivity patterns, countries at an earlier stage of development have the advantage of being a latecomer and can rely on capital, land, resources, and other inputs to promote economic growth. China was in this situation between the 1970s and the 2000s. In contrast, countries at a later stage of development may need to focus on economic growth based on TFP. From the early 2010s, China's economy has evolved from high-speed growth to high-quality development. It is in a critical period of transformation of development mode, optimization of economic structure, and transformation of growth momentum. Rather than look at the impact of coal industry development on GDP, it is more important now to study the impact of coal industry development on TFP in China's coal cities. This provides insight into whether these coal cities are structurally locked into dependence on coal and are not able to diversify their economies.

Based on a preliminary diagnosis, domestic coal supply and demand show significant spatial dislocation. The negative correlation between the enrichment of coal resources and regional economic development suggests that China may have an interprovincial coal "resource curse." After China's economic development entered the new normal, the problem of structural excess coal capacity has become prominent. The coal industry has expanded excessively, and the national industrial structure is in urgent need of transformation and upgrading. In 2013, the State Council issued the National Plan for Sustainable Development of Resource Cities (covering the period 2013–2020) to regulate and guide the industrial transformation and development of resource cities. Nevertheless, in 2021 among the 10 cities with the lowest housing prices in China, there were 5 coal cities. A group of resource cities, mainly in coal, represented by Hegang, Shuangyashan, Qitaihe, Shuozhou, and Liaoyuan, had attracted wide attention due to their large population loss and economic depression.

This article therefore explores the relationship between the development of coal industry and the TFP of China's coal cities, investigates the "conditional resource curse" and analyze its influence path, and tries to identify the root cause of the inhibiting effect of coal resources on the quality of urban development, so as to find a way to avoid the coal "resource curse" and promote the sustainable development of China's coal cities.

2. Theoretical analysis and hypothesis

Leaving aside the controversial issue of the impact of natural resources on economic development, scholars have focused more on clarifying the reasons why natural resource endowments do not promote economic development, and have attempted to find corresponding solutions, namely, research on the transmission mechanism of natural resources inhibiting economic development. This research can be mainly divided into 2 categories. One is to study the influence of industrial structure evolution through transmission mechanisms on the relationship between resource industry development and economic development, based on the "Dutch Disease" model. The other approach is to analyze the transmission mechanism of factor allocation efficiency on the relationship between resource industry development and economic development, mainly including research on crowding out effects of important input factors such as human capital (HC), technology, financial capital, and material capital.

In the 1960s, the Netherlands discovered abundant natural gas reserves which were immediately developed and utilized. Massive natural gas exports led to a sharp rise in national income and economic prosperity. But this new wealth has also brought a series of problems that affect the normal operation of the national economy. This phenomenon of abnormal prosperity in the resource sector, known as the "Dutch Disease," is not conducive to economic development (Corden and Neavy, 1982). The "Dutch Disease" model constructed a history of industrial structure evolution caused by the resource sector by studying the flow of labor among the 3 sectors of resources, manufacturing, and service industries. Corden and Neavy's study proves that the development of the resource sector has an adverse impact on residents' income, distribution and the impact of manufacturing size, and profit margins. Later, the "Dutch Disease" model was modified by some scholars (Matsuyama, 1992; Sachs and Warner, 1997).

The development of resource industry has a crowding out effect on key variables that affect the efficiency of factor allocation, such as HC and financial development (FD). In a neoclassical production function, the new growth theory internalizes HC and uses it to explain the reason of sustained economic growth (Lucas, 1988). Due to the low and single skill demand of the labor force in resource-based industries, HC investment cannot be compensated by excess income, resulting in diminishing expected return from the labor force's education and weakening the internal driving force of HC accumulation. Insufficient accumulation of HC in resource-rich countries and regions will lead to the lack of long-term economic growth momentum and trigger the "resource curse" effect.

Endogenous FD theorists believe that the effective development of finance fosters economic growth by promoting the accumulation of physical capital and improving the efficiency of capital allocation (King and Levine, 1993). High resource endowment reduces savings and investment by inhibiting the development of the financial sector, which has an indirect effect on the "resource curse" (Gylfason and Zoega, 2006). Liu et al. (2015) verified the threshold effect of FD in the impact of natural resources on economic development by using the "Dutch Disease" model. Dividends from coal have a smoothing effect on consumption, taking away the incentive to build a more efficient financial system. The development of the coal industry has crowded out the technology and investment of the financial system, and the weakening effect of the system has inhibited the sound institutional system necessary for the FD. Tang (2019) studied from the perspective of behavioral finance and believed that precipitated costs would distort financial resource allocation.

Consequently, the occurrence of the "resource curse" is conditional (Song and Yang, 2019). The evolution of industrial structure and the efficiency of factor allocation will affect the relationship between natural resources and economic growth. Most of the research on the transmission mechanism of industrial structure evolution is based on the "Dutch Disease" model, but the model assumes that the output of all economic sectors only comes from the input of labor. This is inconsistent with the actual operation of the coal industry. At present, most of the relevant literatures on the transmission mechanism of factor allocation efficiency are based on empirical evidence, through reexamination of the "resource curse" hypothesis that natural resources inhibit economic development to study the crowding out effect on economic variables that affect factor allocation efficiency. However, the different development paths of resource industries in different regions lead to different transmission paths of "resource curse," so it is necessary to study this problem more specifically.

2.1. The transmission mechanism of industrial structure evolution

The "Dutch Disease" model is based on the "dependent economy" model used to analyze a series of phenomena that are unfavorable to economic development caused by the prosperity of natural resources. In the "Dutch Disease" model, resources and manufacturing are defined as tradable sectors, and services as nontradable sectors, and 3 types of commodities are produced in a small open economy, among which resources and manufacturing sectors produce tradable goods, while services are not tradable.

Suppose there is a coal sector, a manufacturing sector, and a service sector in a small open economy. The coal sector and the manufacturing sector are tradable sectors, and taking into account the assumption of open markets that prices in tradable sectors are exogenous to the prices of products from small open economies, prices of services products in nontradable sectors move flexibly depending on supply and demand within the economy. There are only 2 input production factors in each sector, labor and capital. The production factors can flow freely among various sectors. Factors of production cannot move across economies. Prices are perfectly elastic. The products of each sector are homogenized, and all final products are used only for consumption. The manufacturing sector has the characteristics of "learning by doing" and has technology spillover effects. The coal sector uses the technology spillovers from the manufacturing sector for free.

The phenomenon of transferring production factors from other industrial sectors to the coal sector due to the increase in the marginal output of production factors in the coal sector is called the "transfer effect." This transfer effect is recognized as "direct deindustrialization" (**Figure 1**).

The initial development of the coal industry provides a sustainable income for residents in coal cities for a period of time, and the disposable personal income increases.

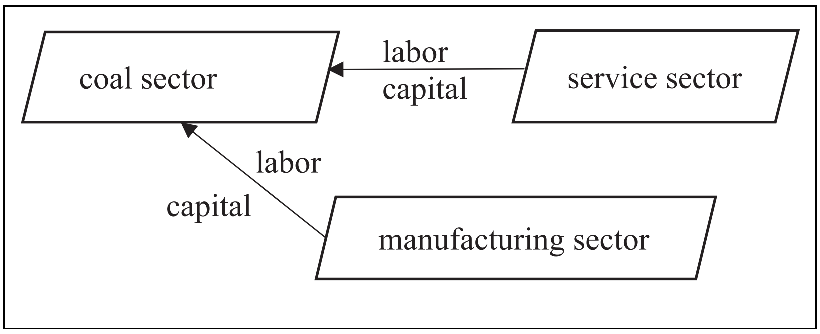

Figure 1. Transfer effect of the "Dutch Disease" model.

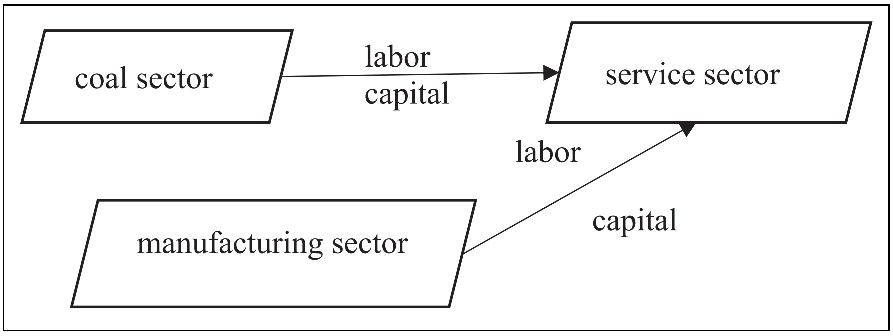

Figure 2. Expenditure effect of the "Dutch Disease" model.

When the demand for the service and manufacturing sectors in the region increases, the transfer effect reduces the supply of the service sector. The service sector cannot obtain new supply outside the region due to its nontradability, and excess demand will inevitably lead to price increases. The demand for labor in the service sector increases in order to raise the standard of supply. The wages of the service sector have to rise to attract labor from the coal sector and the manufacturing sector to the service sector. The service sector also tends to obtain more capital at a higher cost. The difficulty and cost of obtaining funds for manufacturers have also increased, and they have to raise the wage level. In an open market environment, the increased demand for manufacturing by consumers in small open economies can be met by increasing supply and importing by the regional manufacturing sector. The prices of products in the manufacturing sector are determined exogenously by the international market, and it is impossible to make up for the rising cost of production factors by raising prices. The profitability of the manufacturing sector will decline, and the scale and competitiveness will gradually decrease. Over time, the service sector will bloom again, while the manufacturing sector continues to shrink.

The shrinking of the manufacturing sector due to the decline in the level of output and factor input, which is caused by the developing coal industry and transmitted through the service sector is called "indirect deindustrialization" (**Figure 2**).

As the growing coal industry inhibits the development of the manufacturing industry and disrupts the industrial structure, coal cities lock in a coal-based economy. Even when the influence of the prosperity of coal resources is gradually eliminated, it is difficult for economic growth and technological progress to automatically return to the original growth path.

To sum up, in the revised "Dutch Disease" model, the transfer effect and the expenditure effect combined affects small open economies in the following ways. Firstly, the output of the manufacturing sector and the input of production factors decrease significantly. Secondly, the combined effects of the output of the coal sector and the service sector and the input level of production factors are uncertain. The third way is the increase in the cost of production factors. **Table 1** summarizes the impact of the coal resource boom on the various economic sectors discussed in the "Dutch Disease" model.

Through analysis of this "Dutch Disease" modified model, we find that the development of coal industry is a process, at the beginning of which it brings "sacred food" to the area and provides raw materials for manufacture. The economy of the region is booming in the short term. When the coal industry continues to prosper, the production factors from the manufacturing and service sectors are taken away. The resource dividend generated by the development of the coal industry stimulates the demand for products in the nontradable service sector. The expenditure effect appears, and the factors of production from the manufacturing and coal industries turn to the service sector. Both evolution of industrial structures hurt manufacture, which has a "learning by doing" character and can lead to TFP growth in the economy. This evolution of industrial structure is one of the reasons why the development of coal industry in coal cities has an inverted U-shaped nonlinear effect on their TFP.

Table 1. The impact of the "Dutch Disease" on various sectors

		Output	Labor	Capital	Cost	Price
Transfer effect (direct deindustrialization)	Coal sector	+	+	+	+	0
	Manufacturing sector	−	−	−	+	0
	Service sector	−	−	−	+	+
Expenditure effect (indirect deindustrialization)	Coal sector	−	−	−	+	0
	Manufacturing sector	−	−	−	+	0
	Service sector	+	+	+	+	+
Combined effects (double deindustrialization)	Coal sector	?	?	?	++	0
	Manufacturing sector	−−	−−	−−	++	0
	Service sector	?	?	?	++	++

+, −, 0, ? means rising, falling, unchanged, and uncertain.

2.2. Transmission mechanism of factor allocation efficiency

Labor and capital are the main input production factors. The developing coal industry does not benefit the factor market and reduces the allocative efficiency of production factors. The "Dutch Disease" modified model analyzes the evolution of the industrial structure caused by the development of the coal industry through the transfer and expenditure effects of labor and capital among various sectors. But this model only analyzes the quantity of labor and capital input; the impact of coal industry development on the efficiency of labor and capital allocation has not been considered.

Romer (1990) added HC and simple labor to the production function separately. It is believed that the key to the efficiency of labor market allocation is HC. Insufficient HC investment in the coal sector not only reduces the production efficiency of this sector but also has a negative impact on the HC structure of other sectors, especially the manufacturing sector, reducing the production efficiency and product competitiveness of the entire society. The substantial development of the coal industry reduces the need for personal savings and investment. It also provides a stable source of income for residents in coal-based areas for a period of time. And such residents will not raise their savings or investment in the current state to cover their expense in later life. Areas with abundant coal resources usually give priority to the development of the coal industry, and the imperfect financial industry indirectly hinders the growth of investment and savings and therefore is not conducive to the development of the capital market.

Suppose that in a free and competitive closed economy, the main decision-makers are firms and resident consumers. The allocation of production factors is determined by the firm. Resident consumers with homogeneity and notion of infinite time satisfy their own demand through consumption and provide labor inelastically.

The utility function of resident consumers is built using the constant relative risk aversion utility function form in the Ramsay Model. In an infinite time domain ($\sigma \neq 1$), the standard optimal residential consumer programming is as follows:

$$U(c) = \int_0^{\infty} \frac{c^{1-\sigma} - 1}{1 - \sigma} L e^{-\rho t} dt = \int_0^{\infty} \frac{c^{1-\sigma} - 1}{1 - \sigma} e^{-\rho t} dt \quad (1)$$

where $c = C/L$ represents per capita consumption, C is the total consumption, L for family size. The total population remains the same and the total is standardized to 1; ρ ($\rho >$ 0) is the subjective discount rate; σ ($\sigma \geq 0$) is the relative risk aversion coefficient, which is the reciprocal of the intertemporal elasticity of substitution. $e^{-\rho t}$ is the discount factor, which is used to reflect the importance of resident consumers to future consumption.

The economic growth theory holds that on the path of balanced economic growth, the growth rates of material capital K, total output Y, and consumption C are the same. Assuming no depreciation of physical capital and constant population size, the steady-state growth rate of each variable is equal to TFP g_A.

$$g_C = g_A = g_Y = g_y \quad (2)$$

Household consumption level g_c is used as a measure of TFP g_A. The relationship between household consumption level g_c and coal resource input can be used to examine the relationship between TFP and coal industry development. Constructing the Hamilton function and finding the maximum value gives the Ramsey rule:

$$g_c = \frac{\overset{\Delta}{c}}{c} = \frac{r - \rho}{\sigma} \quad (3)$$

where r is the rate of return on capital, and capital receipts can be divided to material capital receipts r_k, natural capital receipts r_n, HC receipts r_h, and financial capital receipts r_f. Assuming that there is a complete market, labor can flow freely, and consumers have equal returns on various assets. That is, in the equilibrium state, r_k, r_n, r_h, and r_f are equal to the rate of return on other capital.

The decision-making outcome of the economic agent tends to be consistent with the returns of various factors. Therefore, r can be regarded as the average value of various types of returns on capital of resident consumers.

Under equilibrium conditions, the following results can be obtained:

$$r=\frac{(r_k+r_n+r_h+r_f)}{4} \tag{4}$$

Human capital and simple labor to the production function are added separately. Assuming constant returns to scale, coal firm realizes output through the input of physical capital *K*, coal resources *N*, human capital *H*, financial development *F*, and labor *L*. Set the production function of the coal firm in the form of the Cobb-Douglas production function:

$$Y=AK^{\alpha}N^{\beta}H^{\gamma}F^{\lambda}L^{1-\alpha-\beta-\gamma-\lambda} \tag{5}$$

where *A* is Solo residual; α, β, γ, λ are parameters to be determined. The firm's profit function can be constructed:

$$\Pi=Y-r_kK-r_nN-r_hH-r_fF-\omega L \tag{6}$$

In a competitive market, according to Equation 6, *K*, *N*, *H*, and *F* are used to calculate the first-order derivative of *N*, and the conditional equations for maximizing the profit of coal firms can be obtained:

$$\begin{cases} r_k=f_K(K,N,H,F,L)=\alpha AK^{\alpha-1}N^{\beta}H^{\gamma}F^{\lambda}L^{1-\alpha-\beta-\gamma-\lambda}\\ r_n=f_N(K,N,H,F,L)=\beta AK^{\alpha}N^{\beta-1}H^{\gamma}F^{\lambda}L^{1-\alpha-\beta-\gamma-\lambda}\\ r_h=f_H(K,N,H,F,L)=\gamma AK^{\alpha}N^{\beta}H^{\gamma-1}F^{\lambda}L^{1-\alpha-\beta-\gamma-\lambda}\\ r_f=f_F(K,N,H,F,L)=\lambda AK^{\alpha}N^{\beta}H^{\gamma}F^{\lambda-1}L^{1-\alpha-\beta-\gamma-\lambda}\end{cases} \tag{7}$$

In the equilibrium state, various types of capital investment returns are equal, and combined with the conditional Equation 7, we are able to get:

$$\begin{cases} K/N=\alpha/\beta\\ H/N=\gamma/\beta\\ F/N=\lambda/\beta\end{cases} \tag{8}$$

where *K/N* is the allocation rate of physical capital per unit of coal resources, *H/N* is the allocation rate of HC per unit of coal resources, *F/N* is the allocation rate of financial capital per unit of coal resources, and β is the degree of coal industry development. Combining the conditional Equations 8 and 4, we are able to get:

$$r=\frac{1}{4}Y\left(\frac{\alpha}{K}+\frac{\beta}{N}+\frac{\gamma}{H}+\frac{\lambda}{F}\right) \tag{9}$$

Substituting Equation 9 into Equation 3, we are able to get:

$$g_c=\frac{1}{\sigma}\left[\frac{1}{4}Y\left(\frac{\alpha}{K}+\frac{\beta}{N}+\frac{\gamma}{H}+\frac{\lambda}{F}\right)-\rho\right] \tag{10}$$

Assuming that a certain economic variable is a threshold variable in the influence of coal industry development in coal cities on TFP, there must be a threshold value that makes the correlation between coal resources *N* and residents' consumption levels g_c change on both sides of Equation 10. By taking the first-order derivative and second-order derivative of coal resources *N* on both sides of Equation 10, the threshold value can be obtained. Combined with Equation 8, the second-order partial derivative of coal resources *N* can be simplified to obtain:

$$\frac{\partial g_c}{\partial N}=\frac{1}{4\sigma}Y\left(\frac{\alpha\beta}{KN}+\frac{\beta(\beta-1)}{N^2}+\frac{\beta\gamma}{NH}+\frac{\beta\lambda}{NF}\right) \tag{11}$$

$$\frac{\partial^2 g_c}{\partial^2 N}=\frac{\beta(\beta-1)}{4\sigma}\frac{Y}{N^3}(4\beta-2) \tag{12}$$

We start from analyzing the HC constraints in the process of coal industry development promoting the improvement of TFP in coal cities. If the influence of coal industry development in coal cities on TFP is constrained by human capital *H*, taking physical capital *K* as an invariant, and making the first-order derivative (11) of residents' consumption level to coal resource *N* equal to zero, we can obtain:

$$H^*=\frac{\gamma K}{(1-\beta)\frac{K}{N}-\alpha-\frac{\lambda K}{F}} \tag{13}$$

Combining the Equation 8, the threshold value of HC is:

$$H^*=\frac{\beta\gamma K}{\alpha-3\alpha\beta} \tag{14}$$

Similarly, if the way in which the development of the coal industry affects the TFP of coal cities is subject to the threshold of financial progress, the threshold value of FD can be derived from the same operation as above:

$$F^*=\frac{\beta\lambda K}{\alpha-3\alpha\beta} \tag{15}$$

Because α, β, γ, λ are all numbers between (0, 1), and *K* is greater than zero, the threshold values *H**, *F** of Equations 14 and 15 are positive, $0<\beta<\frac{1}{3}$ must be established. And because *Y*, *N*, and σ values are all greater than zero, Equation 12 of the second-order derivative of residents' consumption level g_c to coal resource *N* is always greater than zero. Therefore, it can be considered that there is a threshold value *H**, *F** so that the function of the production sector on coal resources takes the minimum value. On both sides of the threshold value, the influence of the development of coal industry in coal cities on TFP changes from negative to positive, showing an inverted U-shaped relationship of influence.

The development of a resource industry will crowd out the development of HC and finance. If the inhibitory effect of coal industry development on HC and FD does not exceed a certain threshold range, the positive contribution of coal industry development in coal cities to TFP is sufficient to alleviate or eliminate these adverse effects. These positive contributions include providing the necessary material basis and energy for the improvement of TFP. And coal products can bring resource dividends through external market transactions. The dividend effect in **Figure 3** shows that the development of the coal industry increases the residents' income in coal cities, promotes capital accumulation, increases the fiscal budget, and integrates the remaining production factors, which promotes the TFP of coal cities.

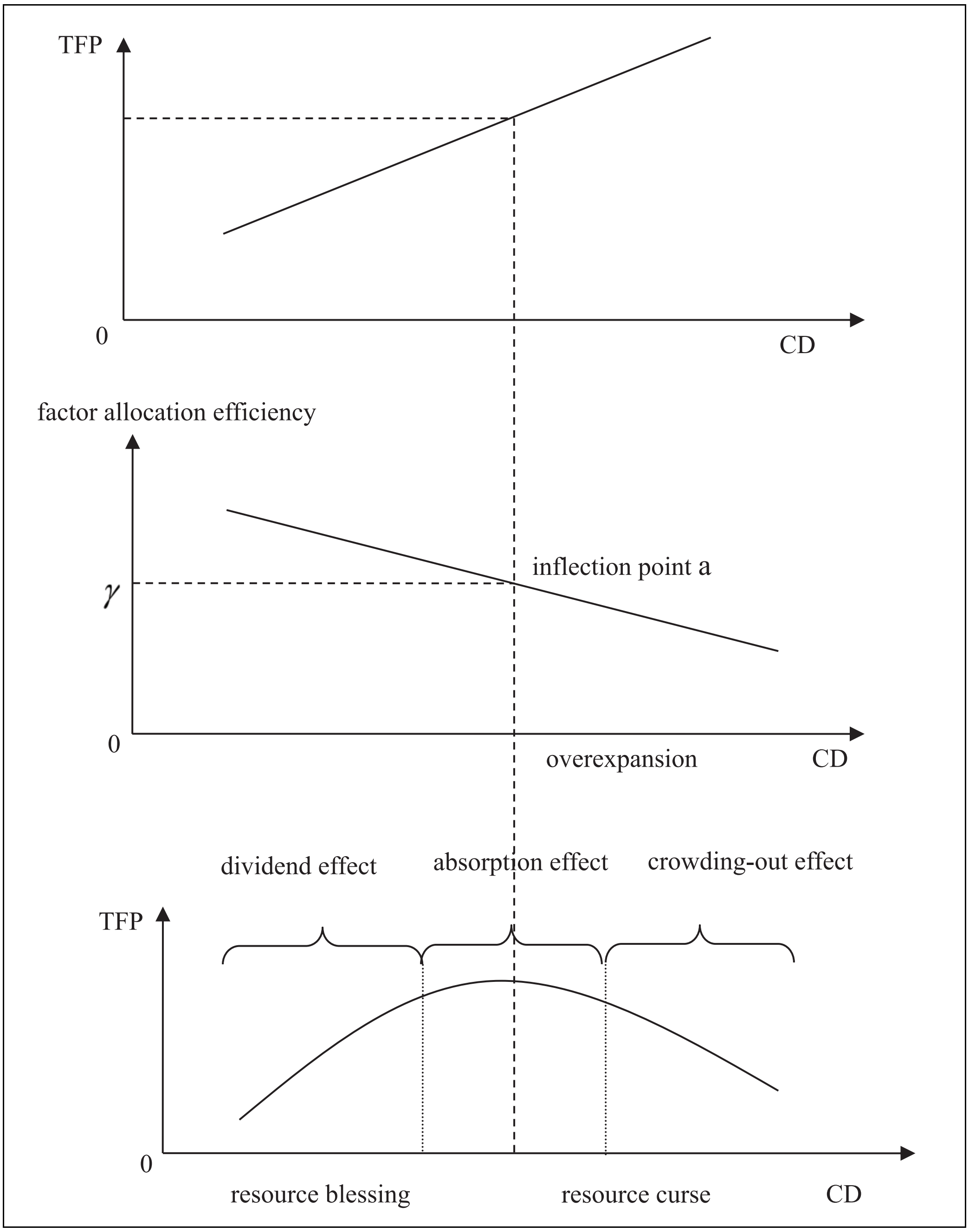

Figure 3. Transmission mechanism of factor allocation efficiency.

But if coal cities continue to overexploit coal resources and focus on developing the coal industry, they will inevitably absorb the limited economic factors such as labor and capital into the coal sector in large numbers, and continue to lock up labor and capital at the low end, crowding out the HC and FD that can improve the efficiency of factor allocation. The absorption effect in **Figure 3** indicates that the development of the coal industry has weakened the cultivation of key factor markets that affect the TFP of coal cities, and the crowding out effect has become more prominent. When the crowding out of HC and FD from the development of the coal industry exceeds the corresponding threshold γ, the positive impact of the development of the coal industry in coal cities on TFP is swallowed up by the crowding out effect.

The crowding out effect in **Figure 3** shows that underdeveloped labor and capital markets due to low levels of HC and FD. In the transformation of the coal industry, a large number of surplus labor force are generated. They are single-skill and pay little attention to the input of HC in the early stage so are seldomly qualified for other jobs. The local labor market is stunted and cannot provide more positions, resulting in its inability to place larger number of employees. Plants, equipment, and other fixed assets in the industry cannot be converted into ready money quickly through the capital market during the transformation process, which also increases the precipitated cost of the coal industry. When the sunk cost is too high, coal firms are reluctant to realize short-term losses caused by development path alteration. Coal firms with low operating efficiency and declining profitability will continue to maintain their existing interests and cooperative relationships. And they cannot adjust excess capacity through negative investment, which will eventually lead to excessive expansion of the coal industry and inhibit the TFP of coal cities.

It can be seen that, under the influence of factor allocation efficiency, the combined effect of dividend effect and the absorption effect and crowding out effect, the nonlinear impact of coal industry development in coal cities on TFP is formed. When the dividend effect is dominant, the development of the coal industry shows a side that is beneficial to the TFP of coal cities, thus manifesting as a "resource blessing"; when the absorption effect and the crowding out effect are dominant, the sunk cost rises, leading to excessive expansion of the coal industry where the "resource curse" effect occurs.

The inverted U-shaped impact of coal industry development on TFP shows that the inhibitory effect of coal industry development on TFP is not inevitable. Through theoretical analysis, it is proved that HC and FD are the threshold variables for the development of coal industry to affect the TFP of coal cities. When the level of HC and FD is low, the development of the coal industry will inhibit the TFP of coal cities, which is manifested as the "resource curse"; when the level of HC and FD is high, the development of the coal industry will promote the TFP of coal cities, which is manifested as "resource blessing."

Based on the above analysis, the following 4 hypotheses can be put forward:

Hypothesis 1: The development of the coal industry in coal cities has a nonlinear impact on TFP. The promotion and inhibition of coal industry development on urban TFP coexist, and the emergence of inhibition is conditional.

Hypothesis 2: The evolution of the industrial structure caused by the development of the coal industry affects the development of the service industry and the manufacturing industry, so that the development of the coal industry in coal cities has an inverted U-shaped nonlinear impact on TFP.

Hypothesis 3: Human capital is the threshold variable for the influence of coal industry development in coal cities on TFP. On both sides of the HC threshold, the impact of coal industry development on TFP in coal cities changes from negative to positive.

Hypothesis 4: FD is the threshold variable for the influence of coal industry development in coal cities on TFP. On both sides of the FD threshold, the impact of coal industry development on TFP in coal cities changes from negative to positive.

3. Model and empirical test

3.1. Data description

A coal city is born and gains its prosperity from coal as a resource, by developing its coal mining and washing industry. The coal city has a unique mining structure, and the ratio of the gross domestic product of coal and washing industry to the regional gross domestic product is more than 10%. There are more than 20,000 employees in the coal and washing industry, accounting for no less than 3.51% of the total employees at the end of the year. Raw coal output is higher than 10 million tons/year. According to this standard, this article takes the list of 126 resource prefecture-level cities determined in the National Plan for Sustainable Development of Resource Cities (2013–2020) as the sample frame, and uses the data of each city for preliminary screening. Considering the particularity of regenerative and declining resource cities, the quantitative standard is appropriately relaxed. Finally, 44 coal cities are selected as the research object of this article. This article uses the sample panel data of 44 coal cities in China from 2003 to 2017 to conduct an empirical test. The data comes from the "China City Statistical Yearbook"; a small number of missing data were filled in through the province's statistical yearbook, the city's statistical bulletin or the use of linear interpolation. In this article, we use GDP deflator to deal with the original data related to price in the variable, and use 2003 as the base period to convert it into comparable price. The specific measures and descriptive statistics of the variables are summarized in **Table 2**.

Total factor productivity reflects the overall efficiency level of transforming major economic input factors into final output, which is conducive to comprehensive analysis of economic development and is an important basis for formulating long-term sustainable economic development policies. The current mainstream measurement methods can be divided into 2 types: parametric method and nonparametric method. Parametric method includes Solow residual method, expanded Solow residual method, random frontier production function, and other methods. Nonparametric method includes exponential method, data envelopment analysis, and other methods. The "Solow residual" is derived from the C-D production function, which is the part of the surplus that cannot be explained by factor input in economic growth. This article is a theoretical analysis based on the C-D production function. Only by using the Solow residual method to estimate TFP can the conclusions drawn from the theoretical analysis be verified. Therefore, this article will use the Solow residual method to estimate TFP.

The commonly used metrics for coal industry development (CD) include the employment ratio, output value ratio, and investment ratio of mining industries. However, the data for Chinese cities only include the number of employees in the mining industry. Therefore, this article, like other literature that studies the "resource curse" of coal cities, uses the proportion of mining industry employees to the total number of employees to measure the development of the coal industry in China's coal cities. Due to the large fluctuations in the data on the proportion of employees in the mining industry, the logarithmic ratio of the proportion of employees in the mining industry is used here.

Government intervention (GI) is measured by the ratio of fiscal expenditure to GDP after deducting science and education expenditure. Technical innovation investment

Table 2. Qualitative description and measurement of variables in the model

Variable	Symbol	Metrics and Description	Unit	Mean	*SD*	Min.	Max.
Total factor productivity	TFP	Solow residual method	%	0.0231	0.1094	−0.2849	0.5240
Coal industry development	CD	Logarithm of employment in mining	%	0.2152	0.1161	0.0279	0.5813
Government intervention	GI	Public finance expenditure after deducting science and education expenditures as a percentage of GDP	%	0.1359	0.0648	0.0334	0.4730
Technological innovation	TI	Employment ratios in scientific research, technical services, and geological exploration	%	0.0115	0.0056	0.0029	0.0500
Service industry development	SD	Proportion of employees in the tertiary industry	%	0.4899	0.1150	0.225	0.7663
Manufacturing development	MD	Proportion of employees in manufacturing	%	0.1668	0.0862	0.0227	0.5360
Financial development	FD	Year-end loan balance of financial institutions as a percentage of GDP	%	0.1396	0.0550	0.0415	0.4541
Human capital	HC	The proportion of employees in the education industry	%	0.7120	0.3869	0.2218	6.1930

(TI) is characterized by the employment ratio of scientific research, technical services, and geological exploration industries. Service industry development (SD) and manufacturing industry development (MD) are measured by the proportion of employees in the tertiary industry and manufacturing industry, respectively.

The commonly used FD indicators in existing research include the ratio of private credit to GDP, the ratio of current liabilities to GDP, and the ratio of deposits and loans to GDP. Limited by the availability of urban data, many scholars also use the financial deepening index, that is, the ratio of the year-end loan balance of financial institutions to GDP, to measure the level of FD. This article aims to empirically test the transmission role of capital allocation efficiency in the impact of coal industry development on TFP in China's coal cities. Using the financial deepening index to measure FD is more reasonable. But good investments tend to generate more loans, so there may be reverse causal effects.

The measurement of HC can be measured using labor remuneration from the perspective of output and performance; from the perspective of investment, it can be measured using educational attainment index, education funding investment, and average length of education. Theoretical analysis has demonstrated that the key factor that affects the development of the coal industry in the allocation of labor efficiency among various departments of the labor market is HC. This article regards HC as the proxy variable for labor allocation efficiency, and the input and accumulation of HC are the key factors that affect the development of the labor market. Therefore, HC should be measured from the perspective of investment, but data on education levels at the urban level in China are not available. The education level of workers in coal cities is generally not high, and the net outflow of talent caused by underdeveloped education affects the accumulation of HC. It is reasonable to use the proportion of education workers to measure HC in coal cities.

3.2. Metering of the "Conditional Resource Curse"

Sachs and Warner (1999) set up a classical regression model to study the relationship between natural resources and economic development, and established a standard logic paradigm for the empirical study of the "Resource Curse." That is, the process of natural resources prosperity promoted or inhibited the behavior of *Z*, and *Z* is the key variable which affects economic development. We will use the classical models of Sachs and Warner to construct our econometric model of the impact of CD on TFP, which is also the process of selecting the control variables with key influence according to our theoretical analysis and relevant research. We regard the institutional environment and technological progress as exogenous variables. In the econometric model the GI and TI are introduced as control variables, to empirically test the nonlinear impact of CD on TFP.

According to the "conditional resource curse" regression model established by Shao and Yang (2014) a static panel regression Model 1.1 is constructed to test hypothesis 1:

$$\mathrm{TFP}_{it} = \alpha_{10} + \alpha_{11}\mathrm{CD}_{it} + \alpha_{12}\mathrm{CD}_{it}^2 + \alpha_{13}\mathrm{GI}_{it} + \alpha_{14}\mathrm{TI}_{it} + \varepsilon_{it} \quad (1.1)$$

where α is the parameter to be estimated, ε_{it} is the random perturbation term, and *i* and *t* represent the individual and time, respectively.

Table 3. Estimation results of Model 1.1

Variable	Two-Way Fixed Effect	Fixed Effect	Random Effect	Ordinary Least Square
CD	0.2305*** (0.0637)	0.2638*** (0.0700)	0.0199* (0.0452)	0.0191* (0.0437)
CD^2	−0.0500*** (0.0125)	−0.0617*** (0.0137)	−0.0039* (0.0080)	−0.0036* (0.0077)
GI	−0.2827*** (0.1019)	−0.6186*** (0.0794)	−0.1738*** (0.0561)	−0.1491*** (0.0543)
TI	3.1631*** (0.9695)	2.4871** (1.0464)	0.9071* (0.6990)	0.8348 (0.6727)
_cons	0.7531*** (0.0823)	0.7526*** (0.0903)	0.9111*** (0.0651)	0.9078*** (0.0631)
R^2	0.4897	0.3100	0.2747	0.2124
Obs	660	660	660	660
F value	0.0000	0.0000	0.0349	0.0000
Inflection point	2.3050	2.1378	2.5513	2.6528
Curve	∩	∩	∩	∩

*, **, *** mean significant at the 10%, 5%, 1% significance levels.

By estimating α_{11} and α_{12} in Model 1.1, we can judge the nonlinear influence of CD on TFP. If α_{11} and α_{12} are significantly non-zero, when $\alpha_{11} > 0$ and $\alpha_{12} < 0$, CD has an inverted U-shaped effect on TFP, and when CD is lower than the inflection point, it shows the state of "resource blessing." When coal industry expands excessively and exceeds the inflection point, the "resource curse" effect appears. When $\alpha_{11} < 0$ and $\alpha_{12} < 0$, CD has a U-shaped effect on TFP. When CD is lower than the inflection point, TFP will be suppressed, and if it exceeds the inflection point, TFP will be promoted.

In order to verify the existence of a "conditional resource curse" in China's coal cities, Model 1.1 needs to be regressed to clarify the nonlinear relationship between the two. In order to verify the robustness of the results, two-way fixed effect regression, fixed effect regression, random effect regression, and ordinary least square regression were used to test Model 1.1. The regression results are summarized in **Table 3**.

The *F* values of the parameters obtained by the 4 regressions are all tested, which shows that the estimation results of Model 1.1 are robust. It is also necessary to determine the regression model to use to interpret the regression results. The commonly used *F*-test can determine whether the ordinary least square or the fixed effect model should be chosen.

The test result shows that the *P* value is 0.0001; the strong rejection of the original hypothesis indicates that the fixed effect is obviously superior to the ordinary least square. The Hausman test is used to determine whether the regression results should be interpreted using a fixed effect model or a random effect model. The Hausman test has a *P* value of 0.0000, which strongly rejects the original hypothesis. The fixed effect model should be used to explain the regression results. One-way fixed effects solve the problem of missing variables of individual differences, and two-way fixed effects introduce time fixed effects to solve the problem of missing variables of time differences. In the two-way fixed effect regression, the sign of time effect is negative; except for 2004, all the dummy variables are significant. The joint significance of all dummy variables is tested, and the *P* value is 0.0000, strongly rejecting the original hypothesis of "no time effect." We therefore choose the two-way fixed effect to explain the regression result of Model 1.1.

The regression results of the two-way fixed model show that the regression coefficient of CD is 0.2305, and the regression coefficient of CD^2 is −0.0500. Hypothesis 1 is verified, that is, CD have a nonlinear effect on TFP, and the occurrence of the "resource curse" effect is conditional. All the control variables have passed the test, which shows that the selected control variables have different degrees of impact on the TFP, and the impact is consistent with the results of most related studies.

The regression coefficient for GI is −0.2827. The government's fiscal support policy has protected backward production capacity, reduced the motivation of enterprises to innovate, lowered the efficiency of factor allocation, and inhibited TFP. The unclear property rights of coal resources have led to rent-seeking and corrupt behaviors in the governments and industries of coal cities (Zhao et al., 2021). It exacerbates the inhibitory effect of CD on TFP.

The regression coefficient for TI is 3.1631. Technological innovation has improved the regional innovation capability and technological progress level, and significantly promoted the TFP. Investment in technological innovation activities such as technology research and development funds and personnel can promote regional innovation and improve economic efficiency. The economic development of coal cities relies heavily on the endowment of coal resources. The development and utilization of coal resources are mostly in the initial stage, the technology used is relatively backward, and the demand for high and new technology is insufficient. The crowding out of TI by CD inhibits the upgrading of industrial institutions and is not conducive to the improvement of TFP.

CD has an inverted U-shaped nonlinear impact on TFP, with an inflection point of 2.3050, which is reduced to a mining employment ratio of 10.02%. The "conditional resource curse" in the dimension of TFP exists. Whether CD is a "blessing" or a "curse" to the urban economic development efficiency depends on the degree of CD reflected by the proportion of employment in the mining industry.

Differentiated by the "curse" inflection point, the 44 sample coal cities can be divided into 2 key categories. In 2017, there were 33 sample cities in the "resource curse" state, including all declining coal cities and a large number of mature coal cities in major coal producing provinces such as Shanxi, Shaanxi, and Heilongjiang. The development of coal industry in these cities mainly depends on the endowment of coal resources, and the development of modern manufacturing industry is significantly lagging behind. High tech industries are still in the initial stage, with low innovation levels, and weak agglomeration capabilities of production factors such as HC and financial capital, making it difficult to support and ensure development of the new industry. It is worth noting that the growing coal cities represented by Ordos and Liupanshui have entered the fast lane of coal industry development due to their natural coal resource endowment, but their rapid development has triggered a series of economic problems, damaged their industrial structure, and sharply increased demand for services and real estate industries with nontradable sector characteristics. Service industry has flourished, housing prices have skyrocketed, and the factor costs of manufacturing have increased, restraining the development of the manufacturing industry. Due to insufficient demand, underdeveloped markets, and high exit barriers in the labor and capital markets, there is a risk of excessive expansion of coal industry.

In 2017, by contrast, there were 11 sample cities in the "resource blessing" state, including Hulunbeier, Chifeng, Xuzhou, Suzhou, Pingxiang, Tai'an, Jiaozuo, Chenzhou, Dazhou, Zhaotong, and Weinan. For example, in Xuzhou, coal industry has successfully transformed, established a long-term mechanism for sustainable development, and freed itself from the coal-based economic growth mode. Development of the coal industry has promoted its TFP, achieving high-quality economic development. As growth coal cities, Hulunbeier and Zhaotong have relatively rich reserves of coal resources, and the comprehensive utilization of coal resources has not yet been fully formed, which is conducive to rational planning of their industrial layout, guiding investment in various factors, giving full play to the advantages of latecomers, and successfully avoiding the "resource curse." Mature coal cities, such as Handan, Chifeng, Suzhou, Tai'an, Chenzhou, Dazhou, and Weinan, transform coal resource advantages into high-quality economic development momentum by controlling the development scale of coal industry and making rational use of coal resources.

Presently, the problem of "resource curse" in the dimension of TFP in China's coal cities is still very serious, and the over expansion of coal industry is prominent. In the context of high-quality development, the coal industry needs to continue to deepen this reform. Under the joint efforts of the government and enterprises, the industrial structure should be adjusted, the development of labor and capital markets should be promoted, precipitated costs should be reduced, and the dilemma of excessive expansion of coal industry in coal cities that restricts the TFP should be resolved.

Figure 4 shows the trend of the number of "resource blessing" coal cities from 2003 to 2017, because the number of "resource blessing" coal cities is relatively small and easy to be summed up and analyzed. The "resource curse" coal cities are moving in the opposite direction; there is not much to explain here. The number of "resource blessing" coal cities showed a U-shaped trend in general, reaching the lowest value in 2011, with only one "resource blessing" coal city, after which the "resource curse" situation was eased somewhat. This shows that the "resource curse" is not inevitable but is conditional and can be circumvented.

3.3. Empirical test on transmission mechanism of industrial structure evolution

The test of Hypothesis 2 refers to the mediation effect test method to construct a recursive equation to test the combined effects of SD on CD one by one. By examining the impact of SD on the curve inflection point, it analyzes its transmission role in the nonlinear impact of CD on TFP.

The first step is to build a baseline regression model. Model 1.1 is used as the basis to examine the impact of CD on TFP, because TI is characterized by the employment ratio of scientific research, technical services, and geological exploration industries, while scientific research,

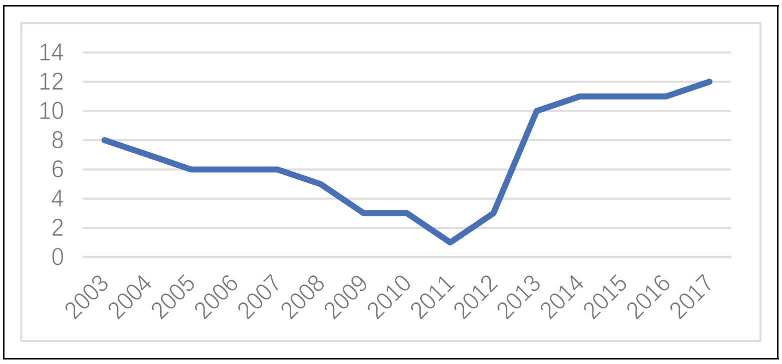

Figure 4. Changes in the number of "resource blessing" coal cities.

Table 4. Test results of the transmission effect of industrial structure evolution

Model	Model 2.1	Model 2.2	Model 2.3	Model 2.4	Model 2.5
Variable	**TFP**	**SD**	**TFP**	**MD**	**TFP**
CD	0.1857*** (0.0627)	−0.0261*** (0.0081)	0.1917*** (0.0613)	−0.0850*** (0.0064)	0.2025*** (0.0612)
CD^2	−0.0427*** (0.0124)	–	−0.0420*** (0.0122)	–	−0.0407*** (0.0121)
GI	−0.2660*** (0.1026)	–	−0.4151*** (0.1040)	–	−0.4180*** (0.1036)
SD	–	–	0.3523*** (0.0657)	−0.4132*** (0.0319)	0.4365*** (0.0735)
MD	–	–	–	–	0.2012** (0.0804)
_cons	−0.1517** (0.0775)	0.5658*** (0.02419)	−0.3336*** (0.0830)	0.6218*** (0.0262)	−0.4519*** (0.0952)
R^2	0.4771	0.6663	0.5103	0.5849	0.5175
Obs	660	660	660	660	660
F value	0.0000	0.0000	0.0000	0.0000	0.0000
Inflection point	2.1745	–	2.2821	–	2.3712
Relationship	∩	↘	∩	↘	∩

*, **, *** mean significant at the 10%, 5%, 1% significance levels.

technical services, and geological exploration industry are a part of the SD and will cause endogenous problems with the SD. Therefore, TI is eliminated in Model 2.1, and the regression model is established as follows:

$$TFP_{it} = \alpha_{20} + \alpha_{21}CD_{it} + \alpha_{22}CD_{it}^2 + \alpha_{23}GI_{it} + \varepsilon_{it} \quad (2.1)$$

The second step is to test the influence of CD on SD in the transfer effect and expenditure effect in the "Dutch Disease" model, and build a regression Model 2.2:

$$SD_{it} = \beta_{10} + \beta_{11}CD_{it} + \varepsilon_{it} \quad (2.2)$$

The third step is to introduce SD into Model 2.1, test the combined effect of SD in the "Dutch Disease" model, and test the impact of SD on the inflection point of the relationship between CD and TFP. If the inflection point of the curve increases after controlling the difference in SD, it means that the difference in SD is the reason for aggravating the effect of the "resource curse," otherwise, it alleviates the "resource curse." The regression model is as follows:

$$TFP_{it} = \alpha_{30} + \alpha_{31}CD_{it} + \alpha_{32}CD_{it}^2 + \alpha_{33}GI_{it} + \alpha_{34}SD_{it} + \varepsilon_{it} \quad (2.3)$$

The "Dutch Disease" model analyzes the development process of the coal industry, which produces a "double deindustrialization" crowding out effect on MD that inhibits TFP. The recursive equation is constructed according to the mediating effect test. By examining the impact of MD on the curve inflection point, it analyzes its transmission role in the nonlinear impact of CD on TFP.

The first step is to use Model 2.3 as a baseline regression model to test the effects of the expenditure effect and the transfer effect on MD.

The second step is to test the transfer effect of CD in the "Dutch Disease" model and the effect of CD on MD through the expenditure effect of SD, and construct the following regression model:

$$MD_{it} = \beta_{20} + \beta_{21}CD_{it} + \beta_{22}SD_{it} + \varepsilon_{it} \quad (2.4)$$

In the third step, MD is added to Model 2.3 to test the deindustrialization effect in the "Dutch Disease" model. Testing the impact of MD on the inflection point of the relationship between CD and TFP, if the inflection point of the curve increases after controlling the difference in MD, it means that the difference in MD is the reason for aggravating the effect of the "resource curse." Otherwise, the "resource curse" is alleviated. The regression model is as follows:

$$TFP_{it} = \alpha_{40} + \alpha_{41}CD_{it} + \alpha_{42}CD_{it}^2 + \alpha_{43}GI_{it} + \alpha_{44}SD_{it} + \alpha_{45}MD_{it} + \varepsilon_{it} \quad (2.5)$$

When testing Model 1.1, the time dummy variable was tested for co-significance, and the null hypothesis of "no time effect" was rejected, and the two-way fixed effect was selected to test the model. Therefore, Models 2.1 to 2.5 also use the two-way fixed effect regression model instead of using multiple regression methods for robustness testing. The test results are shown in **Table 4**.

It can be seen from the regression results of Model 2.1 that the regression coefficient of CD is 0.1857, and the regression coefficient of CD^2 is −0.0427. CD has an inverted U-shaped effect on TFP, which is significant at the 1% statistical level. Model 2.2 judges the impact of CD on SD. From the regression results, the regression coefficient of CD in Model 2.2 is −0.0261, indicating that CD slightly inhibits SD, and the transfer effect of coal industry development on the production factors of the service industry is slightly greater than the expenditure effect.

Model 2.3 tests the influence of SD on TFP and the inflection point. When the SD variable is added, the regression result of Model 2.3 has no structural change, the regression coefficient of CD is 0.1917, and the regression coefficient of CD^2 is −0.0420. The regression coefficient of SD is 0.3523, which proves that SD promotes TFP. The inflection point rose slightly from 2.1745 to 2.2821. It shows that the "resource curse" effect is alleviated after controlling the difference of SD in the model.

It can be argued that the current situation of the service industry has to some extent intensified the inhibiting effect of the development of coal industry in China's coal cities on their TFP. In the "Dutch Disease" model, the conduction function of the service industry is that the expenditure effect of service industry development transfers the production factors from manufacturing industry and coal industry, which makes up for the snatching of the production factors in the transfer effect of the development of the coal industry. However, the overall effect is that the net loss of production factors leads to CD inhibiting SD, and intensifies the inhibition of CD to TFP.

Model 2.4 examines the effects of CD and SD on MD. From the regression results, the regression coefficient of CD in Model 2.4 is −0.0850, indicating that CD inhibits MD. The transfer effect and expenditure effect of coal industry development on production factors of manufacturing industry produce a "double deindustrialization" effect on manufacturing industry. The regression coefficient of CD in Model 2.2 is only −0.0261, indicating that CD has a crowding out effect on both MD and SD, but the service industry is untradable, and there are some production factors that return from the expenditure effect, so the crowding out of SD is not serious, the manufacturing industry has been squeezed out twice in the transfer effect and the expenditure effect. Thus the inhibitory effect of CD on MD is more serious. In Model 2.4, SD is added as the control variable, and the regression result shows that the coefficient of SD is −0.4132, which verifies the inference in the previous section that the expenditure effect of service industry shifts production factors from manufacturing industry. This shift makes up for the damage of the transfer effect of coal industry to the development of service industry, so it produces "double deindustrialization" in manufacturing industry and limits its development.

Model 2.5 tests the influence of MD on TFP and the inflection point. When the MD variable is added, the regression result of Model 2.5 has no structural change, the regression coefficient of CD is 0.2025, and the regression coefficient of CD^2 is −0.0407. The regression coefficient of MD is 0.2012, which proves that MD promotes TFP. The inflection point of the "resource curse" continues to rise from 2.2821 to 2.3712, which verifies that the development of coal industry squeezes out manufacturing industry, and the shrinking of manufacturing industry with the "learning by doing" effect aggravates the "resource curse" effect. It is one of the causes of the inverted U-shaped impact of the development of coal industry in China's coal cities on TFP.

Through empirical testing of Models 2.1–2.5, hypothesis 2 is verified. The evolution of the industrial structure caused by the development of coal industry affects the development of service industry and manufacturing industry, so that the development of coal industry in coal cities has an inverted U-shaped nonlinear impact on TFP. The empirical test shows that the expenditure effect is slightly less than the transfer effect in the combined effect of the service industry in the sample period. An untradable service industry can be developed to a certain extent by the backflow of production factors in the expenditure effect, and the development of coal industry squeezes out service industry. In the "Dutch Disease" model, the transfer effect of the development of coal industry on manufacturing industry and the expenditure effect brought about by the increase of consumption demand leads to the "double deindustrialization" of the manufacturing industry. The development of coal industry has a more restraining effect on the development of manufacturing industry. This kind of industrial structure evolution causes the manufacturing industry to shrink seriously, which has the effect of "Learning by doing" which is one of the reasons why the development of coal industry in China's coal cities has an inverted U-shaped influence on TFP.

3.4. Empirical test of the transmission mechanism of factor allocation efficiency

The test of Hypothesis 3 uses threshold panel regression (Hansen,1999) to establish a single threshold Model 3.1 and a double threshold Model 3.2 to verify the threshold effect of HC. The specific models are as follows:

$$\begin{aligned}\mathrm{TFP}_{it} = {} & \alpha_{50} + \alpha_{51}\mathrm{CD}_{it}I(\mathrm{HC}_{it} \le \gamma_{11}) \\ & + \alpha_{52}\mathrm{CD}_{it}I(\mathrm{HC}_{it} > \gamma_{11}) + \alpha_{53}\mathrm{GI}_{it} \\ & + \alpha_{54}\mathrm{TI}_{it} + \alpha_{55}\mathrm{FD}_{it} + \varepsilon_{it}\end{aligned} \tag{3.1}$$

$$\begin{aligned}\mathrm{TFP}_{it} = {} & \beta_{30} + \beta_{31}\mathrm{CD}_{it}I(\mathrm{HC}_{it} \le \gamma_{21}) \\ & + \beta_{32}\mathrm{CD}_{it}I(\gamma_{21} < \mathrm{HC}_{it} \le \gamma_{22}) \\ & + \beta_{33}\mathrm{CD}_{it}I(\mathrm{HC}_{it} > \gamma_{22}) \\ & + \beta_{34}\mathrm{GI}_{it} + \beta_{35}\mathrm{TI}_{it} + \beta_{36}\mathrm{FD}_{it} + \varepsilon_{it}\end{aligned} \tag{3.2}$$

The test of hypothesis 4 also establishes a single threshold Model 4.1 and a double threshold Model 4.2 to verify the threshold effect of FD. The specific models are as follows:

$$\begin{aligned}\mathrm{TFP}_{it} = {} & \alpha_{60} + \alpha_{61}\mathrm{CD}_{it}I(\mathrm{FD}_{it} \le \gamma_{31}) \\ & + \alpha_{62}\mathrm{CD}_{it}I(\mathrm{FD}_{it} > \gamma_{31}) + \alpha_{63}\mathrm{GI}_{it} \\ & + \alpha_{64}\mathrm{TI}_{it} + \alpha_{65}\mathrm{HC}_{it} + \varepsilon_{it}\end{aligned} \tag{4.1}$$

$$\begin{aligned}\mathrm{TFP}_{it} = {} & \beta_{40} + \beta_{41}\mathrm{CD}_{it}I(\mathrm{FD}_{it} \le \gamma_{41}) \\ & + \beta_{42}\mathrm{CD}_{it}I(\gamma_{41} < \mathrm{FD}_{it} \le \gamma_{42}) \\ & + \beta_{43}\mathrm{CD}_{it}I(\mathrm{FD}_{it} > \gamma_{42}) \\ & + \beta_{44}\mathrm{GI}_{it} + \beta_{45}\mathrm{TI}_{it} + \beta_{46}\mathrm{HC}_{it} + \varepsilon_{it}\end{aligned} \tag{4.2}$$

In Models 3.1–4.2, α and β are the parameters to be estimated, γ is the threshold to be estimated, $I(\bullet)$ is the indicator function, ϵ_{it} is the random perturbation term, and i and t represent the individual and time, respectively.

Estimated under the setting of single or double thresholds for the threshold variables FD and HC, the *F* value and *P* value are summarized in **Table 5**. In this article, the Bootstrap method is used to determine the threshold

Table 5. Results of the significance test of HC threshold effect

	Single Threshold		Double Thresholds			
Threshold Variable	***F* Value**	***P* Value**	***F* Value**	***P* Value**	**Threshold Number**	**Threshold Value**
HC	53.749***	0.000	32.510***	0.000	2	$\gamma_1 = 0.12$, $\gamma_2 = 0.23$
FD	14.767*	0.052	13.656	0.106	1	$\gamma_1 = 1.488$

*, **, *** mean significant at the 10%, 5%, 1% significance levels.

Table 6. Estimated results of HC and FD threshold regression models

Variable	Model 3.2	Variable	Model 4.1
CD ($HC_{it} \leq \gamma_1$)	−0.0221*** (0.0086)	CD ($FD_{it} \leq \gamma_1$)	−0.0361*** (0.0127)
CD ($\gamma_1 < HC_{it} \leq \gamma_2$)	−0.0066 (0.0087)	CD ($FD_{it} > \gamma_1$)	0.0077* (0.0155)
CD ($HC_{it} > \gamma_2$)	0.0379*** (0.0122)	–	–
GI	−0.4182*** (0.0694)	GI	−0.5569*** (0.0743)
TI	0.6266 (0.6631)	TI	0.9174* (0.4665)
FD	0.0199** (0.0096)	HC	1.4317*** (0.1445)
_cons	−0.0095 (0.0307)	_cons	−0.1101** (0.0470)
Obs	660	obs	660
R^2	0.3312	R^2	0.4241
F value	0.0000	*F* value	0.0000
Curve	∩	Curve	∩

*, **, *** mean significant at the 10%, 5%, 1% significance levels.

value, and the likelihood ratio test statistic for overlapping simulations is set to 500 times, get the *F* value, *P* value, threshold number, and its estimated value.

The results show that there are double thresholds for HC, the threshold values are 0.12 and 0.23. There is a single threshold for FD, the threshold value is 1.488. It shows that CD has nonlinear influence on TFP, and the relationship between CD and TFP has structural mutation. According to the number of threshold values, the double-threshold Model 3.2 of HC and the single-threshold Model 4.1 of FD were selected for threshold regression, and **Table 6** summarizes the regression results. According to the threshold value of HC, the sample can be divided into 3 different HC level intervals, and in these 3 intervals, we can test whether the effect of CD on TFP is significantly different. According to the threshold value of FD, the sample can be divided into 2 intervals, and in the 2 intervals of FD level, we can test whether the difference in the impact of CD on TFP is significant.

The regression coefficient of CD is −0.0221 when HC is lower than 0.12, which is tested at the significant level of 1%, indicating that CD inhibits TFP when HC level is low. When HC is between 0.12 and 0.23, the regression coefficient of CD was −0.0066, which did not pass the significance test. When HC is more than 0.23, the regression coefficient of CD is 0.0379, which is tested at the significant level of 1%, indicating that CD promotes TFP with the increase of HC level. This regression result verifies Hypothesis 3. The regression results of each control variable are basically consistent with Model 1.1, so we will not explain it here.

The sample data shows that most of the HC in coal cities is at a low level. The average of HC is 0.1396, far below the HC threshold of CD promoted TFP of 0.23. During the sample period, there were 27 sample cities with an HC mean value lower than 0.12, accounting for 61.36% of the total sample. When HC is below the threshold, CD restrains TFP and the optimal allocation of labor is not reached. The regional wage gap attracts HC, which affects HC accumulation. The rational decision of firms will make capital flow to the material investment option with higher return on investment, and restrain HC investment. In the coal cities, the scale and structure of manufacturing industry have been destroyed, existing manufacturing industry is highly related to coal industry, and the technology spillover of manufacturing industry has been reduced, which is not conducive to the accumulation of HC in the production process.

The key for high-quality economic growth is to change the mode of economic growth from scale-speed development to quality-efficiency development. The urgent problem at present is to improve the level of HC, so that the development of the coal industry in China's coal cities can promote TFP. At the same time, it is necessary to actively seek other ways to improve the efficiency of factor allocation, and make more rational use of coal resources so that it can promote the TFP of coal cities and achieve the goal of high-quality economic development.

From the 2-stage regression results of FD, it can be seen that when FD is less than 1.488, the regression coefficient of CD is −0.0361, indicating that when the level of FD is low, the development of coal industry in coal cities has an inhibitory effect on TFP. The capital market is not well developed and the efficiency of capital allocation is low due to the crowding out of FD by the development of coal industry, which causes the expansion of coal industry in coal cities to restrain TFP. When FD is higher than 1.488, the regression coefficient of CD is 0.0077, indicating that with the improvement of FD level, the development of coal industry in coal cities promotes the improvement of TFP, and the regression coefficients of both intervals have passed the significance test. This regression result validates Hypothesis 4.

From the sample data, most of the current FD of China's coal cities is at a low level, the mean of FD is only 0.7120, and 13.64% of the sample cities have a FD level higher than 1.488. The FD level of China's coal cities has not reached the optimal allocation. When the level of FD crosses the threshold, the economy enters a virtuous circle of healthy development. Improving FD and promoting the development of the capital market in coal cities should be regarded as an effective way to solve the problem of TFP loss in China's coal cities and achieve high-quality economic development.

Compared with the regression results of HC threshold, it is found that the FD constraints of China's coal cities are more serious, and the capital allocation efficiency of most sample cities is too low, which makes CD inhibit TFP. Through the sample data, it is found that the HC level of 14 sample cities exceeds the threshold value, but due to the constraints of FD, the development of the coal industry inhibits TFP. There is no FD constraint in the 2 sample cities, but the low level of HC is the main reason why the development of the coal industry inhibits TFP. It can be seen that in order to break the "resource curse" of coal cities and achieve high-quality economic development, it is necessary to improve the allocation efficiency of labor and capital at the same time, so that the development of the coal industry can promote the TFP.

4. Policy recommendations

China is a country rich in coal resources. Coal has always been China's basic energy source, providing energy security for economic development. However, the development of many coal cities currently faces a dilemma. This article presents a theoretical analysis and empirical test on the nonlinear influence of the development of coal industry in China's coal cities on their TFP. It is concluded that the sustainable economic development of China's coal cities is highly correlated with the development level of the coal industry. The optimization of industrial structure and the improvement of resource allocation efficiency are the keys to achieve high-quality development of a coal city economy. The government should introduce targeted industrial adjustment policies to improve the efficiency of factor allocation, and guide the sustainable development of coal cities by classification according to different life cycle stages, so that coal cities can make better use of the advantages of coal resources to promote the quality of economic development.

4.1. Suggestions on industrial adjustment policies to improve resource allocation efficiency

4.1.1. Adjust the industrial structure and scientifically plan the development of coal industry

Abundant coal resources are not a bad thing. Only the excessive expansion of coal industry in coal cities will inhibit its TFP. Therefore, it is necessary to rationally plan the development of coal industry and promote the adjustment of the cities' industrial structure. The government can formulate policies such as a "mining quota" to raise the entry threshold of the coal industry and eliminate backward production capacity. It can take advantage of the increase in fiscal revenue brought by a new resource tax to provide preferential policies in taxation and finance for non-resource industries such as manufacturing industry, and thereby promote the adjustment of industrial structure. In this way, the government can build a coal industry exit mechanism.

In reviving coal resource-based cities, it is necessary to constantly adjust the direction of transformation and to lead their industrial renaissance with industrial planning that deepens supply-side structural reform and builds a new development pattern of coal industry with both domestic and international markets. For example, the government can promote the development of coal electrochemical integration as part of the modern coal chemical industry. It can fund innovation-driven basic research and establish a new coal industry agglomeration. It can also work to build new labor-intensive industries. Alongside the industrial foundation of coal cities, we should actively develop modern service industries of diverse types.

4.1.2. Accumulate human capital and promote labor market development

Human capital is the foundation of innovation and provides an important factor for technology transformation. The HC level of labor supply determines the innovation and industrial transformation ability of coal cities. Increasing HC investment in coal cities, accelerating the accumulation of HC and cultivating the labor market can more efficiently allocate labor among various industries, so that the development of coal industry can still promote the improvement of TFP. The government should adopt a training strategy that targets the growth of new talents that can support the new industries mentioned above. While strengthening the basic education system, the government should also cultivate the specific HC that matches the local industry's characteristics.

The accumulation of HC is a long-term process. The initiative of HC and individual labor rights mean that HC is different from other production factors and has strong cross-regional mobility. The loss of HC in coal cities to other places in China is serious, so it is necessary to adopt a policy of retaining people and attracting people to meet HC needs in the process of industrial structure transformation. The government must vigorously carry out vocational education and on-the-job training, strengthen the construction of vocational education and training bases, and improve the scientific quality and labor skills of front-line production personnel. China can learn from the successful experience of Japan and other countries to strengthen the skills training of existing workers before the transformation of the coal industry, so that they can quickly transfer to other industries after the transformation of the coal industry, reduce the sunk cost of labor and improve the efficiency of labor allocation.

4.1.3. Actively develop green finance and promote the development of capital market

Capital is a necessary factor input condition for industrial development. The scale, growth rate, availability, and price of capital supply will affect the evolution of industrial structure. On the basis of the capital structure, the ability to access capital determines the speed and scale of industrial development. A well-developed capital market can provide sufficient information, improve the capital structure of enterprises, reduce financing costs and improve the allocation efficiency of factors among various industries. China's coal city economic development level is low, and the shortage of funds is serious. Capital constraints make these regions give priority to the development of coal industry, which requires less capital, while the development of manufacturing industry, which requires more capital, is inhibited. The poor development of the capital market in coal cities makes the development of the manufacturing industry subject to financing constraints, which often leads to manufacturing enterprises with insufficient internal funds, failing to obtain external financing due to the lack of mortgage assets or high financing cost, and thus missing the development opportunity.

In the process of coal industry transformation, green finance should be actively developed. Financial institutions, markets, and government agencies can push capital to those coal enterprises undertaking transformation, and this capital advantage can make industrial upgrading, optimization, and integration become reality. The market system can quickly connect between capital supply and demand, and break through a series of obstacles such as the factor market and the capital market. The government needs to improve the market system to have high efficiency, and to make it easier for coal industry to attract resources at scale in order to meet national carbon policies and realize the sustainable development of economy.

4.1.4. Move forward sustainable growth of the coal industry and actively develop new energy

The green development mode is an important symbol of high-quality economic development and a basic requirement for sustainable social and economic development. In recent years, coal industry has faced serious problems such as high energy consumption, environmental pollution, raw ore depletion, and weak economic growth. Therefore, it is necessary to carry out a multidimensional and multimechanism green transformation of coal industry, and actively develop new energy such as solar and wind energy, according to the resource endowment of coal cities. To achieve the goals of environmental protection, energy saving and efficiency improvement, coal industry should be guided to follow the green development route of clean production, green service, and high-quality. Coal industry should work toward green energy technology innovation, to become more vital and competitive, so as to effectively promote the wealth level of coal cities, and add a new power source for improving the efficiency of urban green transformation. A new coal green price system should be established, including the value of ecological compensation, to enable the efficient use of resources and the effective growth of urban green circular economy.

4.2. Sustainable development path of coal cities based on life cycle

4.2.1. Standardize the orderly development of growing coal cities

Growing coal cities include Shuozhou, Hulunbuir, Ordos, Liupanshui, Yan'an, and Yulin. The development of the coal industry in these coal cities is at an upward stage, with ample economic and social development potential. They are the supply and backup bases for energy in China. However, these cities already face problems such as a single industrial structure and excessive development of the coal industry. The resource development order of growing coal cities should be regulated in a timely manner, the entry threshold for enterprises should be raised, the intensity of resource development should be reasonably determined, and environmental impact assessment requirements should be strictly enforced. A resource sustainable development fund should be established to internalize the cost of environmental restoration and governance due to enterprises. Coal city governments can improve the level of deep processing in coal industry, accelerate the improvement of supporting upstream and downstream industries, actively plan the layout of strategic emerging industries, and accelerate new industrialization. With a long-term perspective, scientific planning, and a reasonable handling of the relationship between coal resource development and urban development, new industrialization and new urbanization can develop together in a coordinated manner.

4.2.2. Promote the leapfrog development of mature coal cities

More than half of China's coal cities are in the mature stage, and their coal resources development is in a stable stage, with strong energy security capacity and high level of economic and social development. They are the core areas of China's coal resources security at the present time. In these cities, it is necessary to efficiently develop and utilize coal resources, raise the technical level of the coal industry, extend the industrial chain, and accelerate the cultivation of a number of leading coal deep-processing enterprises and industrial clusters. It is necessary to form several pillar industries as soon as possible to help these cities diversify for the future. It is also critical to address coal industry's environmental problems at the same time, by targeting mines' environment management and land reclamation after mine closures. These coal cities should also vigorously improving people's livelihoods, speed up the development of social undertakings, enhance the level of basic public services, and improve urban functions.

4.2.3. Support the transformation and development of declining coal cities

Declining coal cities tend to be depleted of financial resources and fall into the "resource curse" state, with lagging economic development, prominent livelihood problems, and great pressure on the environment. They are key and difficult areas in accelerating the transformation of China's economic development mode. Efforts should be made to break the dual structure within these cities, resolve problems left over from their history of coal production, do everything possible to facilitate the reemployment of unemployed miners, actively promote the renovation of rundown areas, and speed up the comprehensive treatment of potential geological disasters such as abandoned mining pits and sunken areas.

Coal cities in their decline period have to face many practical obstacles in the process of withdrawal from coal. A large number of precipitated costs lead to high exit barriers for the coal industry, and relying entirely on the regulatory role of the market will lead to ineffective reallocation of factors. The government should guide inefficient coal enterprises with excessive expansion to stop, limit, or switch production by administrative means, provide technical assistance for these changes, and use fiscal policies to grant subsidies or tax breaks for production conversion. To guide the orderly exit of the coal industry, they can increase policy support, pursue the development of replacement industries, and gradually enhance sustainable development.

4.2.4. Guide the innovative development of renewable coal cities

The renewable coal cities represented by Xuzhou have basically avoided the "resource curse" and started to step into the track of sound economic and social development. Those cities provide promising examples for coal cities to transform the mode of economic development. Renewable coal cities should further optimize their economic structure, improve the quality and efficiency of economic development, deepen the level of opening-up and scientific and technological innovation, transform and upgrade traditional industries, cultivate and develop strategic emerging industries, and accelerate the development of modern service industries. The government should increase spending on improving people's livelihood and promote equal access to basic public services.

Data accessibility statement

The data mainly come from the EPS database and the "China City Statistical Yearbook" and "China Statistical Yearbook" provided by the National Bureau of Statistics between 2003 and 2017.

Supplemental files

The supplementary material for this article can be found online at: http://www.stats.gov.cn/; https://www.epsnet.com.cn/.

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